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THE PRIESTMAN ENGINE AS MANUFACTURED IN AMERICA.

BY COLEMAN SELLERS, E. D.

[*A paper read at the stated meeting of the Franklin Institute, held December 21, 1892.*]

Mr. JOS. M. WILSON, President, in the chair.

MR. PRESIDENT AND MEMBERS OF THE FRANKLIN INSTITUTE:

DR. SELLERS:—In 1890, while in London, I found Prof. William Cawthorne Unwin, B.Sc., F.R.S., interested in his tests of a few internal combustion or explosion motors, using petroleum as fuel, which had been exhibited at the Royal Agricultural Society's Show at Plymouth, in 1889. He called my attention to the fact that among those exhibited, the Priestman engine (*Fig. 1*) not only had worked well, but in cost of running, a small engine of less than ten horse-power compared favorably with the best results that had

been obtained from steam in large low-pressure engines under the most favorable conditions, the price of coal oil being in England in excess of its price in America.

On March 8, 1892, Professor Unwin read a paper on "Petroleum Engines," before the Institution of Civil Engineers, at 25 Great George Street, London. This paper (to be found on the file of this Institute), dwelling mainly on the Priestman engine, is so exhaustive as to questions of economy and efficiency as to leave no room for me to present any better statement on the same subject, further than to say, that I have myself tested the accuracy of many of Professor Unwin's figures. Changes since that time made in the Priestman engine, as manufactured in Philadelphia

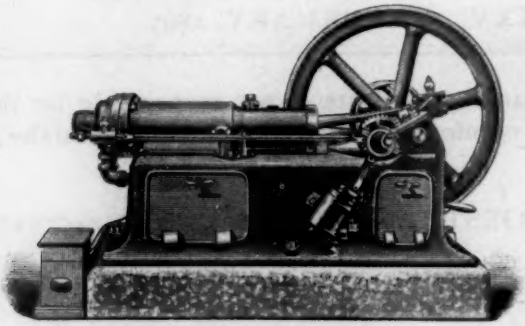


FIG. 1.—English design.

by a branch company for the American market, will be the motive in my presentation of the case now.

Professor Unwin's tests of consumption of oil by the Priestman engine, tried by him in England, extended over a considerable time, and he made these tests upon several different engines. In the tabulated results he gives the relative values of coal oil and coals as heat makers and their ability to yield power, the one, coal oil, applying its heat to air by internal combustion, the coal being burned under a boiler to make the steam that operates a steam engine.

He states that it may be assumed that one pound of oil is thermally equivalent to one and one-fourth pounds of

coal;* so that 0·946 pounds of oil equals 1·18 of coal, 0·988 oil equals 1·23, and 0·842 pounds of oil equals 1·02 pounds of coal, each per effective brake horse-power per hour. He cites as the lowest observed consumption of steam, that a large triple-condensing Sulzer engine worked at high pressure gave a result equal to 1·61 pounds of coal per effective horse-power per hour. It is, indeed, remarkable that better results should have been obtained in an oil engine of only five horse-power, while a steam engine of five horse-power would be considered very economical that would consume three or four pounds of coal per effective horse-power per hour.

I have verified Professor Unwin's figures and have made

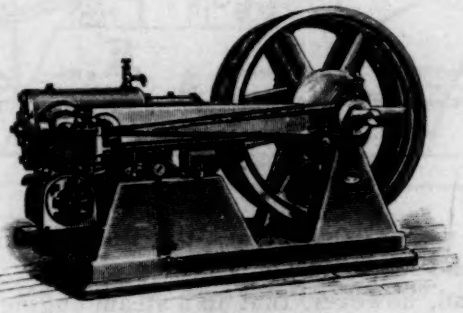


FIG. 2.—American design.

several tests of consumption under unfavorable conditions to get at what may be considered the cost in actual use without any of the careful attention that always accomplishes trial runs with all conditions favorable. In one case, when an engine yielding 8·25 brake horse-power was run for two hours at full load, the engine being set up in an open shed, in very cold weather, with all conditions unfavorable, the oil consumption amounted to 1·159 pounds per horse-power per hour, the oil costing a little over four and three-fourths cents per gallon (say five cents per gallon), and was of a density of ·781; a cubic inch of this oil weighing ·028116 pounds. As 231 cubic inches, or one United

* See Unwin on *Petroleum Engines*, p. 20.

States gallon costs (say) five cents and weighs 6·494796 pounds per gallon of this density, therefore, 1·159 of oil equals ·008923 of a dollar (say $\frac{9}{10}$ of one cent per horse-power per hour). This working at nine mills per horse-power shows that the claim usually made of assuming the cost to be one cent per horse-power is not unreasonable and may be considered as covering oil burned in getting up heat in the mixer before the engine is started.

Professor Unwin, on p. 25, gives a table of cost of working for fuel per hour, from which may be taken:

COST OF FUEL PER HOUR.

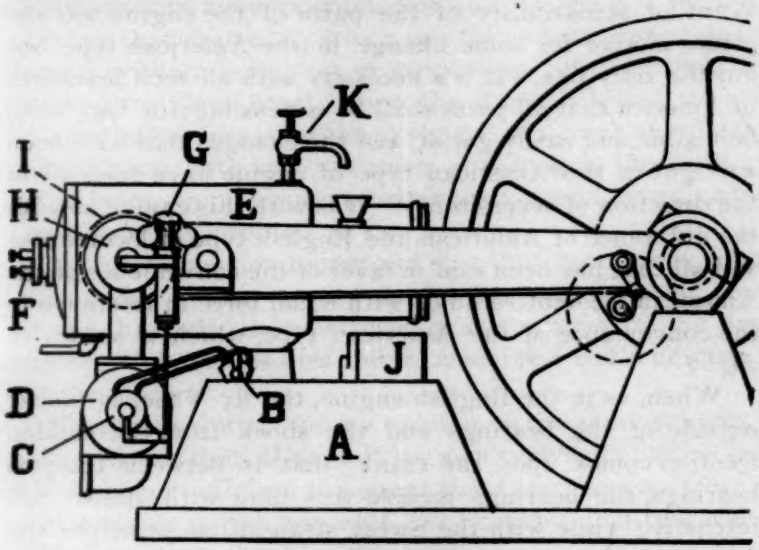
Engine.	Per Effective Horse-power.		
	Quantity of Fuel.	Price.	Cost.
Large condensing steam engine, . .	2 pounds.	$4 00 a ton.	·36 of a cent.
Small non-condensing steam engine,	6 pounds.	4 00 a ton.	1·08 cents.
Gas engine, ...	24 cubic feet.	1 50 per M.	3·60 cents.
Priestman engine, ...	1 pound oil.	2 38 barrel.	·75 of a cent.

With us, in the experiment cited, the Priestman engine was run at the cost of ·89 of a cent per hour. It must be borne in mind, however, that in a steam engine the cost of the stoker must be added, and most small steam engines use more coal than cited. There is also more fuel wasted in getting up steam or keeping up steam while standing than there is wasted in the oil engine, which requires no attention whatever while running, save to keep the oil in the tank, and when standing costs nothing.

The Priestman engine must not be compared with a steam engine and boiler as to first cost. It is a power-producing machine of a different type, considered as a superior and unique machine, and its real value is measured by deducting from its total first cost when erected all the savings it is capable of effecting as compared to power obtained from steam.

Professor Unwin, in his paper, mentioned the fact of these changes having been introduced in the American

form of the Priestman engine, but did not go very deeply into the details of construction as he had not, at that time, seen the American machine.



SYSTEM OF OPERATION.

A, oil tank filled with any ordinary high test (usually 150° test) oil, from which oil under air pressure is forced through a pipe to the *B* three-way cock, and thence conveyed to the *C* atomizer, where the oil is met by a current of air and broken up into atoms and sprayed into the *D* mixer, where it is mixed with the proper proportion of supplementary air and sufficiently heated by the exhaust from the cylinder passing around this chamber. The mixture is then drawn by suction through the inlet valve *I* into the *E* cylinder, where it is compressed by the piston and ignited by an electric spark passing between the points of the *F* ignition plug, the current for the spark being supplied from an ordinary battery furnished with the engine, the *G* governor controlling the supply of oil and air proportionately to the work performed. The burnt products are then discharged through the *H* exhaust valve, which is actuated by a cam. The *I* inlet valve is directly opposite the exhaust valve. The *J* air pump is used to maintain a small pressure in the oil tank to form the spray. *K*, Water jacket outlet.

By this system a perfect combustion of oil takes place.'

Fig. 1 shows the Priestman engine as examined by Professor Unwin, and you will observe that it differs in no respect from the ordinary engines that are made with the cylinder

and bearings attached to a massive bed plate. In this case the bed plate is made hollow and has much of the working machinery within the casting, and inconvenient for repairs. Want of accessibility of the parts of the engine was the prime motive for some change in the American type, but not the only one. It is a necessity with all such machines in America that all parts shall be accessible; in fact, shall be visible and easily got at, and the changes that have been wrought in the American type of engine have been all in the direction of accessibility. It is with this engine as with the difference of American and English type of locomotive, and all that has been said in favor of the convenience of the American locomotive holds with equal force in reference to the convenience of the American type, which is shown in *Fig. 2.*

When, as in the English engine, the fly wheel is placed outside of the bearings and the shock from the sudden ignition comes upon the crank; that is, between the two bearings, the bearings receive this blow with almost full intensity; while with the Sweet straight-line principle, the fly wheels forming part of the crank, and offering their great weight to the blow between the bearings, they present a mass of sufficient inertia to neutralize the effect of the blow, and this is an illustration of the well-known case of the difference in personal comfort between endeavoring to crack a hickory nut on one's knee, with or without the intervention of a flat-iron or pound weight to serve as an anvil and neutralize the blow of the hammer.

When Mr. Albert Priestman, of the firm of Priestman & Co., came to Philadelphia to introduce the engine in America, he fortunately had for his advisers such able men as our fellow-members, our past president, Mr. Wm. P. Tatham, and Mr. Henry G. Morris. The latter called attention to what Professor Sweet was doing with his straight-line principle steam engine and explained the advantages to be gained by applying the same principles to an engine that at one period of its operation—at the instant of explosion—is subjected to a momentary strain several times greater for that moment, than can

occur in a steam engine of the same nominal size from the steam acting expansively as supplied from a boiler. A petroleum engine of (say) ten horse-power at the moment of explosion may have its crank pin able to resist a force as great as that exerted by steam in a thirty horse-power steam engine, without being out of proportion. By adopting the Sweet principle of construction, the strength called for can be obtained at less cost than by the use of a crank of ordinary construction with other marked advantages, the built-up crank being, in my opinion, better than a solid crank, tooled out of a rough forging.

In this connection I must add that Professor Sweet, when consulted not only approved of what was proposed, but offered his help in constructing some parts of the first engines, so far as his own special machinery could be spared for the purpose.

When called upon for my opinion on the same subject, I endorsed all that Messrs. Priestman's advisers had recommended, and promised to present the American type (*Fig. 2*) of the engine to the notice of the Franklin Institute when the proper time should come.

This time has now come. In presenting the new form I do so with satisfaction, as it serves to illustrate the adaptation of a machine to the American market, which had already an established reputation in England for several years, with such marked deviations from the English model as to make the contrast striking.

This is one of the many examples of mechanical design modified to suit what at first may seem a question of the taste or fancy of a foreign market, but this reason for change is not the true one, and the lesson is rather instructive.

American machine tools differ in many respects from the English type from which they may have sprung, and in America has originated a new line of machine tools peculiar to the country and well adapted to the habits of our workmen. Some of these special tools favor construction in machinery not common in older countries, the opposition to the use of such tools coming partially from the conserva-

tism of the workmen as well as from the difference in machinery used. In the present case, the readiness with which the engineers of the English house accepted the new type for the American market, speaks very highly for their good judgment, for in this machine, which is to be described to you, there are such marked deviations in form and arrangement of parts as to make the difference between the two machine designs not only very striking, but with this change in form of machine there has been, with the American engines from the start, a greater piston speed obtained and consequently higher efficiency for machines of the same weight and size of cylinder.

In bringing the Priestman oil engine to its present state of perfection, there must have been a long period of experimentation, and some of the changes will presently be noted, but all that has been established by the ingenuity of the originators and sustained by their careful experiments in England has been preserved in the American type, the difference being only in the general arrangement and disposition of the parts, as well as some changes in the material used, taking advantage of American experience in engine building generally, and that gained by the makers of this special engine during the period which has elapsed since the engines were first placed on the market.

Professor Unwin's paper was on "Petroleum Engines," and the engine we are considering this evening has been known as a petroleum engine, so also may any engine be called a petroleum engine, which uses petroleum or the products of petroleum, either as a fuel or as the motive-power of the engine. The name, however, conveys to the mind the idea that petroleum vapor is what operates the engine, which would be the case, if the petroleum was really expanded from a liquid into a gaseous form and used under pressure to act upon the piston of a steam engine, and as in point of fact naphtha engines act by the vapor of naphtha. When some portion of the petroleum product is consumed to vaporize another portion of the same product, and the gas so created does act expansively in the cylinder, and is afterwards condensed to be used over

again, as in naphtha engines, such a process comes directly in the category of a petroleum or naphtha engine, and no other name could be well applied to it.

In the present case the petroleum is a fuel only. It is not vaporized so as to make a permanent gas, which can act expansively, but it does impart heat to air and renders it capable of performing the function of a true gas under pressure.

In the first place I wish to have you clearly understand the position in which the Priestman engine stands in relation to all others using coal-oil products, not only as regards its efficiency, but also as regards its absolute safety in fire risks, owing to the clever method of consuming the oil without previously converting it into a fixed gas.

This will be better understood when I mention that in the largest engines only the $\frac{1}{250}$ part of a pint of this high test oil is used at any one time, and in the smallest sizes the fuel is prepared in correct quantities varying from $\frac{1}{7000}$ of a pint upwards, according to whether the engine is running on light or full duty. I think this fact alone demonstrates to a remarkable degree how wonderfully accurate are the system and devices which have been patiently worked out in the Priestman engine to have resulted in it obtaining a good name for itself, as it has done, in unskilled hands and for such a variety of uses. Of course, in gas, gasoline or naphtha engines, the gas has only to be taken into the engine in the right quantity, but in this case the working agent being heavy oil, each charge must be first carefully prepared.

Not very long ago, a lecture was delivered in this hall on "The Compressed Air of the Future," by Mr. Wm. L. Saunders, calling your attention to the wasteful method of using compressed air as a motive-power, and in the beginning of his lecture he stated that compressed air for motive-power purposes, was not necessarily air that had been compressed by mechanical means, but that air at atmospheric pressure confined in a close vessel and sufficiently heated would indicate upon a pressure gauge an expansive force according to the amount of heat imparted to that air. If

air is compressed mechanically heat is developed and the heat manifested is in proportion to the amount of compression. Heat applied to confined air results in expansion and pressure so that if heat is applied, say internally, to confined air expansive force is developed without mechanical compression.

If you will take the trouble to read in the *Franklin Institute Journal* the report of that lecture, and compare it with what I will show you this evening, you will, I think, come to the conclusion that this engine is not actuated by petroleum, but that it is properly an air engine using petroleum as fuel, on the correct principle of application of the heat with the least loss.

In the present case the function of the oil is to heat and expand the air, and as you will presently see, the method of controlling the power of the engine or governing its speed, is by varying the amount of fuel burned and the amount of air that is heated by each regulated charge of fuel and air. This is a case precisely analogous to that of a hypothetical steam engine which receives steam from a boiler fitted with all modern automatic contrivances, whereby the amount of combustion is regulated by the work to be done, so that the amount and pressure of steam generated may be varied each moment to suit the force required; but, with this important distinction that in the Priestman engine are avoided the danger and complications arising from low water, dirty water, foaming boiler, leaky joints and all other incidents attending the operation of converting water into steam and conveying it to the engine.

The Priestman engine uses for fuel common petroleum such as is burned in lamps, and the quality best suited to this purpose is just what is safest in common use; that is, the highest proof oil. This oil is ignited in combination with air under a low pressure, created by the return stroke of the piston. Some part of this air supports the combustion of the oil, and the heat generated by the combustion of the oil expands the air that remains and the products resulting from the explosion, and thus develops its power

from air that it takes in while running. In other words, the engine exerts its power by inhaling air, heating that air and expelling the products of combustion when done with.

You all know that high-proof oil is not highly inflammable, and to bring this fact clearly before your minds, I have in these two porcelain dishes, two petroleum products; in one some of the oil commonly used in the Priestman engine; in the other some of the lighter products of petroleum equivalent to what is employed in the naptha engines. In the case of the oil, a lighted taper presented to its surface shows no indication of ignition and in point of fact the taper can be extinguished readily by immersing it in the fluid oil if the vessel was deep enough. In the other case, a lighted taper brought to the locality, the whole mass bursts into flame from the ignition of the inflammable vapors that are continually escaping from all these lighter hydrocarbons.

When oil is burned in a lamp it does not necessarily ignite very quickly when the match is applied to the wick. The full intensity of the light, in fact, is not given off by a lamp until the wick and adjacent parts are sufficiently heated to cause a rapid evaporization of the petroleum that is drawn up in the wick by capillary attraction. When heated, the gas will burn more actively than when cold. Coal or wood must also be heated up to a certain extent before either will ignite, but when coal is finely pulverized, made into a powder or dust and mixed with air, it will ignite much more readily than when in a large mass, and one of the methods of using coal for fuel quite successfully, tried in some instances, is to pulverize the coal and discharge it in dust form mixed with air into the furnaces where it burns actively in the same manner that oil divided minutely by an atomizer will burn when the same oil will not burn in a solid stream projected into or through the flame of a lighted lamp.

I can show you the action of the atomizer that is used in the Priestman engine to reduce the oil that is required for fuel into the form of dust that it may more readily be ignited, by means of the piece of apparatus which is used

U of M

in testing certain parts of each engine and chiefly in adjusting the spray-maker.

I ought here to state that a very valuable feature of this atomizer is, that it is constructed so that its adjustment is not alterable or necessary to be altered in the hands of users.

By pumping air into the chamber containing oil, it will press on the surface of the oil contained in the chamber, and a fine stream of oil, driven out by the air pressure, can be thrown from the nozzle, and you will observe that holding a lighted candle to this jet, not only does not ignite it, but it may extinguish the flame of the candle. We now have attached to the same nozzle, the device used in the engine for converting this stream of oil into finely divided particles, mixing these particles with air. The ejected oil ceases to be a solid stream, it is broken up by the counter-current air and there is a mingled spray expelled from the apparatus; in fact, a cloud of oil dust. Approach a light to this spray and it instantly ignites and burns with a roaring flame.

This spray formed by the current of compressed air conveyed by a pipe from the air space in the oil tank is not a gas. This can readily be proved by means of a small bottle with an opening in the side besides the usual neck of the bottle. Presenting this side opening to the spray-maker, so as to catch the out-coming air and oil dust, the oil is caught in the bottle and the air separating from the spray passes out through the neck of the bottle. You can readily see the action of the oil falling to the bottom of the bottle, while a taper applied to the neck where the air is escaping does not ignite the air that escapes separate from the oil. This shows that the spray is merely a mechanical mixture of oil and air, each liable to separate from the other if they are given time to come to rest.

If we were to attempt to introduce this spray into the cylinder of the engine and there ignite it, we should find that the oil had passed back into the condition of solid oil, just as is done in the bottle, and ignition could not be effected by the

electric spark. To prove this to be the case, I will ignite the vapor by the same kind of spark from the same battery that is used with the engine to ignite the charge at each stroke. The spark ignites the spray while mixed with the air, but the same kind of spark applied to the air escaping from the bottle, as in the former experiment, produces no ignition whatever, nor will this same spark applied under the oil surface ignite the oil in its fluid condition.

To insure the divided oil and air, mixed in the proper proportion, to remain long enough mixed, it is necessary that it should be moderately heated. To start the engine the mixer used in connection with the cylinder is warmed by the flame of a lamp, using oil dust and air in form of spray, to enable the first charge to be ignited, after which the heated products of combustion escaping from the cylinder are utilized to keep this chamber to its required temperature, without which heat the oil would drop away from the air, as it did in the bottle, as soon as it enters the cylinder.

Professor Unwin, in his paper, enumerates some of the many attempts to use hydrocarbon oils internally in engines, the invention of some of these processes dating back nearly fifty years, and he shows why the complex constitution of the oil gave rise to practical difficulties.* In converting these oils into vapors, to be introduced into an engine, the high heating and the resolution of the oil into stable gas, left certain tarry products behind that clogged the machinery. Priestman, by using the oil as oil dust in a warm condition, is able to burn that oil precisely as it would be burned in the wick of an oil lamp, and his aim is to burn all the oil, except that in contact with the cooler surfaces of the water-jacketed cylinder. Upon these cooler surfaces, the oil not burned is condensed and furnishes the means of lubrication without clogging the working parts by the formation of any tarry product. Some time ago I was cognizant of a remarkable demonstration of this fact. I had an opportunity to examine one of these engines after a five

* See p. 7, Unwin on *Petroleum Engines.*

and a half weeks' run, and after 2,500,000 explosions had taken place in the cylinder. This engine, when taken apart, showed no perceptible injurious deposit on any part of the inside of the cylinder or in any part that was examined. There was nothing to indicate that oil had been used in it, except the clean well-oiled condition of the cylinder itself. The ignition plug had not even once been removed during this run and the platinum points were as clean as when put in.

In engines of this class, there is a space back of the cylinder, over which the piston does not sweep in its motion.

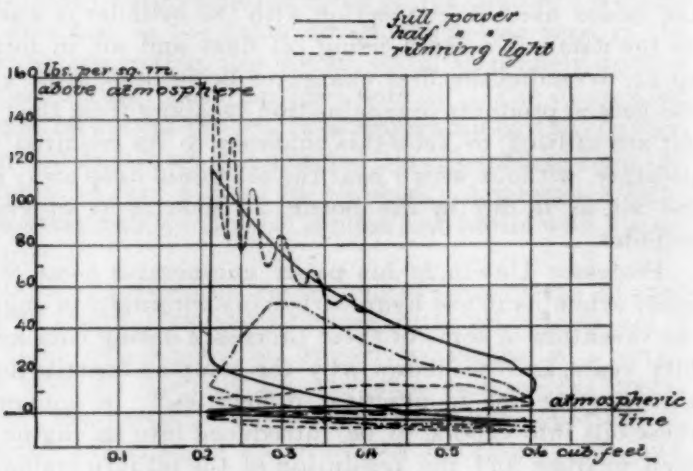


FIG. 3.

This space is a small reservoir, bearing a fixed proportional relation to the whole cubical contents of the cylinder. This space acts as the furnace and boiler that is to operate the engine, and in point of fact is the seat of power of the machine.

The Priestman engine is of the single acting, bi-revolution type ordinary in heat engines. One explosion takes place in each two revolutions of the crank. A charge of air and oil dust, moderately heated, is discharged into the cylinder during the forward motion of the piston, on the return stroke this charge is compressed to less than half its bulk, and explodes while the crank is on its dead centre. The

result is an expansion of air and products of combustion, and these act continuously afterwards at a decreasing pressure during the full forward stroke (*Fig. 3*), and when at the end of that forward stroke, the exhaust valve opens, allowing what remains to escape, and the products of combustion that have not escaped are expelled or swept out by the return stroke of the piston, completing in this way one full cycle. There is a small pressure on the oil tank, sufficient to enable the air to be forced from the cold oil tank, the air from this reservoir, charged with oil dust, passing through the mixer, takes up its due proportion

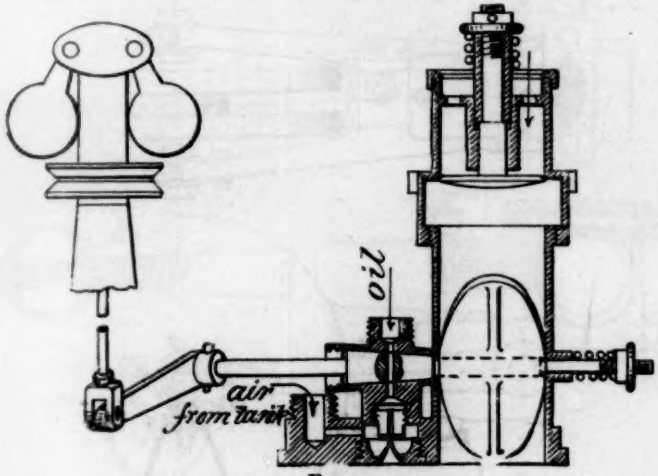


FIG. 4.

of heat, as does also the free air drawn in at the air valves, expands somewhat from the heat imparted to it, a charge enters the cylinder, is compressed and ignited, expanding and thus giving the force required.

The spraying nozzle as now used (*Fig. 4*), and to be explained to you, pulverizes or tears up the oil into very fine atoms, and at the same time protects the mouths of the passages from deposits of carbon which would choke and alter the character of the spray and affect the quantities of the oil and air. It will readily be appreciated that the difficulties which I have mentioned, and which have so long stood in the way of successful kerosene

engines, were not overcome until after numerous trials had been made by Priestman, extending over a period of some years, and which have resulted in a process which, as Professor Unwin correctly states, is "very ingenious and worked out with great scientific skill."

The form of this nozzle was gradually changed. The earliest form, consisting simply of a concentric conoidal mouth-piece, the near or oil mouth-piece being ended in a fine point. After some time it was found better to make the oil nozzle blunt so that the air was turned at a right

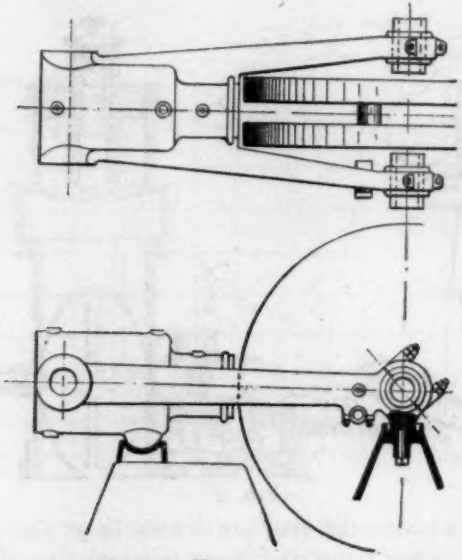


FIG. 5.

angle at the moment of issue, and lastly the form of the air mouth-piece is re-entrant, and the air turns through an angle greater than a right angle at the point of issue of the oil jet.

In the first of these, the oil is forced into and through an escaping column of air. Gradually the nozzles were shortened, and changes made to make the union a much more violent action until finally the air nozzle was turned back towards the oil nozzle, so that the current of air within the nozzle turned towards the escaping stream of oil. In other

words, the air is actually blown in against the escaping oil, and the two thus brought into violent conflict are driven out into a spray of the required condition.

The regulation of the engine by governor to effect the variation of power called for by varying demands, is effected by varying the oil supply and not, as is the case in most gas engines, by suppressing some of the explosions. The spindle which regulates the feed of the oil in the spray-maker also regulates the supplementary air by means of a wing valve.

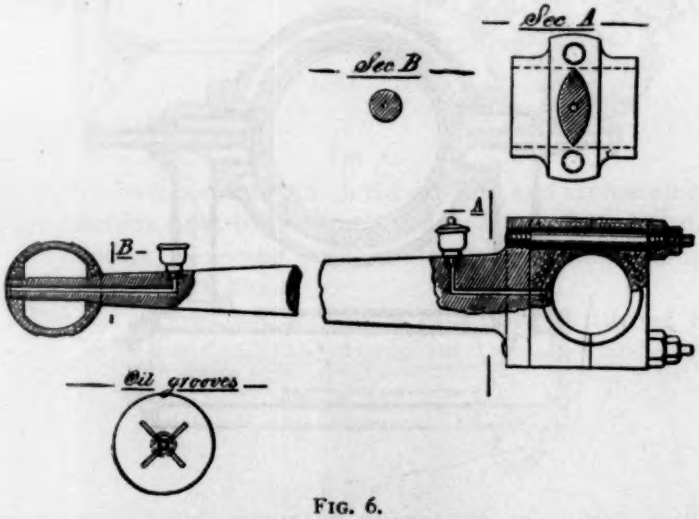


FIG. 6.

In general appearance the engine will at once be recognized as modelled on the straight line principle.

The foundation plate (*Fig. 5*) acts the part only so far as forming a support, but advantage is taken of the rear support by making it large enough to serve as a convenient oil tank, holding a supply for from fifteen to twenty hours full load.

The cylinder and frame (*Fig. 5*) are cast in one piece, the cylinder being water jacketed, the arms hollow of box section. These arms carry the main bearing boxes. Near the back end of the cylinder are ports for the reception of the inlet and exhaust valve boxes. The cylinder and frame

rests on three points, so that there can be no warping due to settling of foundations, and two bolts are used to secure the frame directly under the main bearings, while the cylinder end of the engine rests on the oil tank in a spherical seat, thus allowing free expansion and contraction.

The crank and fly wheel are precisely the same as in the straight line steam engine, and are peculiarly well adapted to this class of engine, as the shock due to explosion is almost entirely absorbed by the wheels, thus taking the wear off the main bearings. As a proof of the perfection

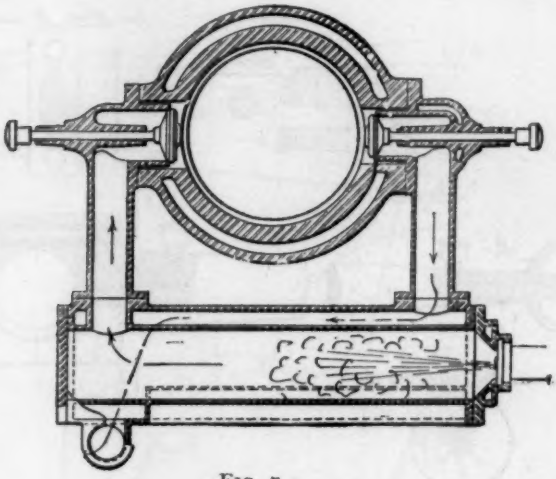


FIG. 7.

of this action, in an engine of eight actual horse-power running daily for over a year, there is not the slightest evidence of any wear having taken place; the grinding marks are still in the shafts and the scraping marks in the babbitt.

The connecting rod (*Fig. 6*) is a steel casting fitted with cast-steel boxes babbitted. It is attached to the piston by a ball joint.

The inlet and exhaust valves (*Fig. 7*) are placed opposite each other near the back end of the cylinder. These are cast-iron poppett valves with cast-iron seat and steel stems of sufficient length to withstand the wear and at the same time remain air-tight with packing or glands.

The exhaust valve is water-jacketed and operated positively by a cam (*Fig. 8*). The inlet valve is opened automatically by the suction of the piston.

The mixer (*Fig. 7*) is a cast-iron jacketed cylinder, around which the exhaust products are allowed to pass, keeping

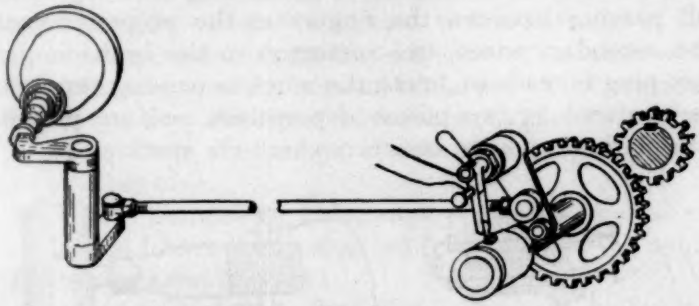


FIG. 8.

the inner chamber, into which the oil dust and air are ejected at a sufficient heat to prevent condensation of the oil dust.

The mixer is swung by connecting pipes from the inlet and exhaust valve boxes.

The air pump (*Fig. 9*) consists of a plunger turned to a proper working fit in the barrel without [illegible]

ERRATUM.

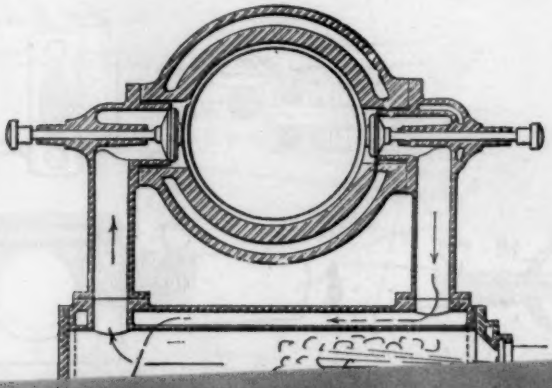
Page 106, last line, for "with" read "without."

FIG. 9.

flap valves are rubber discs, which act noiselessly. The suction valve is provided with a strainer, made of two pieces of perforated brass, with a layer of cotton wool between them, to prevent any dust or grit passing into the oil tank.

rests on three points, so that there can be no warping due to settling of foundations, and two bolts are used to secure the frame directly under the main bearings, while the cylinder end of the engine rests on the oil tank in a spherical seat, thus allowing free expansion and contraction.

The crank and fly wheel are precisely the same as in the straight line steam engine, and are peculiarly well adapted to this class of engine, as the shock due to explosion is almost entirely absorbed by the wheels, thus taking the wear off the main bearings. As a proof of the perfection



The inlet and exhaust valves (*Fig.* 7) are placed opposite each other near the back end of the cylinder. These are cast-iron poppett valves with cast-iron seat and steel stems of sufficient length to withstand the wear and at the same time remain air-tight with packing or glands.

The exhaust valve is water-jacketed and operated positively by a cam (*Fig. 8*). The inlet valve is opened automatically by the suction of the piston.

The mixer (*Fig. 7*) is a cast-iron jacketed cylinder, around which the exhaust products are allowed to pass, keeping

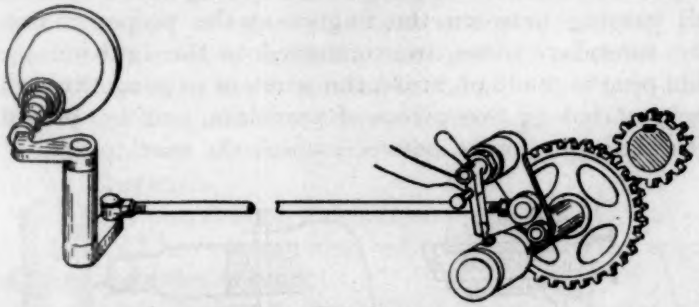


FIG. 8.

the inner chamber, into which the oil dust and air are ejected at a sufficient heat to prevent condensation of the oil dust.

The mixer is swung by connecting pipes from the inlet and exhaust valve boxes.

The air pump (*Fig. 9*) consists of a plunger turned to a proper working fit in the barrel without packing. The

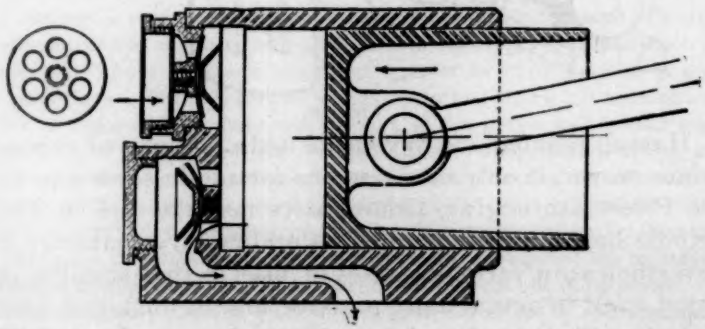


FIG. 9.

flap valves are rubber discs, which act noiselessly. The suction valve is provided with a strainer, made of two pieces of perforated brass, with a layer of cotton wool between them, to prevent any dust or grit passing into the oil tank.

A smaller pump arranged for operation by hand is provided to get up the necessary air pressure for the heater lamp in starting the engine.

The ignition device (*Fig. 10*) consists of either a primary or storage cell and induction coil. The primary wires are attached to a brass fork, the contact being made by a brass ball passing between the fingers at the proper moment. The secondary wires are connected to the ignition plug. This plug is made of brass, the wires in passing through it are insulated by two pieces of porcelain, and are provided with platinum points, between which the spark plays.

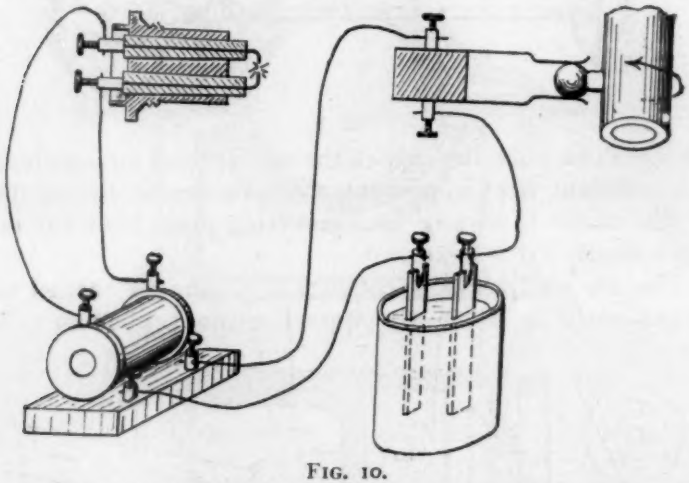


FIG. 10.

Having pointed out to you the main features of this new prime mover, it only now remains for me to show you that the Priestman engine, although its manufacture in Philadelphia has so far been more of a preliminary character, has nevertheless in various classes of uses in this country, procured itself in actual daily practice, and in unskilled hands, to be entitled to the claims in its favor, which I have to-night put before you, or in other words, that it has in this country, and in its new form maintained that good record testified to by Professor Unwin, Lord Kelvin and many others in England and elsewhere.

The Philadelphia Fire Underwriters' Association have

had a full explanation of the functions and mode of operation of this petroleum engine, and have approved its use without any increase whatever in the rate of insurance.

When one of these engines was exhibited at the American Institute Fair the objection that had been held by Underwriters to oil engines in general influenced the managers of the fair to enter objection to the running of this engine in the exhibition until it was proved to their satisfaction that no gas was generated in the process of operating it before ignition, and that there was no danger either from explosion or from the escape of inflammable gas through leaks or otherwise.

With your permission, I therefore propose to read to you a few letters I have lately received from users of the engine in different classes of work:

For Electric Lighting.—Prof. Elihu Thomson writes me:

(Copy.)

THOMSON-HOUSTON ELECTRIC COMPANY.

THOMSON ELECTRIC WELDING COMPANY.

OFFICE OF ELIHU THOMSON.

LYNN, Mass., October 26, 1892.

Dr. Coleman Sellers, 3301 Baring Street, Philadelphia.

MY DEAR SIR:—Yours of the 20th inst. has been received.

I can say in reply to your inquiry that I consider the Priestman oil engine a very convenient engine to run, and that it at the same time gives power at a low cost. I have not made any direct tests of its efficiency so as to state the percentage. The only trouble we have ever had with it has been on one or two occasions when there was a failure of the piston to lubricate itself properly, but I think we will get over that difficulty altogether by mixing our oil, which is the regular 150° test kerosene, with a heavier oil, or one containing paraffines having a very high boiling point. This will adhere to the sides of the cylinder and piston and not be vaporized therefrom by the heat.

I certainly think the engine is a great step in advance of the utilization of comparatively cheap fuels in a scientific manner for obtaining power.

I am using pure silver in place of platinum, not at the igniter electrodes but for the vibrator contacts on the induction coil. It is our experience that pure silver makes a contact which can be relied on to work without getting blackened or coated with a non-conducting substance, such as forms in the case of such metals as platinum. The fact is a slight spark volatilizes a portion of the platinum contacts of the vibrator which condenses as platinum black between them, and in a moderate time destroys the contact, demanding that a cleaning operation be resorted to. We have run our silver contacts

for several weeks without cleaning, and the regularity of action is as perfect as could be desired.

The use of gas for starting we find a very great convenience, as it does away with the flame and smoke in the room when the mixer is allowed to heat up by the oil, and, furthermore, enables us to put on the load of the engine within two or three minutes after starting. We keep the gas on in moderate amount until the mixer is heated up to such a point that the engine can run with the oil alone. We find that it takes about twenty-five cubic feet of gas, as measured by the meter. I think I will be able to reduce this amount considerably by some little changes I am making.

There was, of course, the possibility of the governor of the engine sticking or the belt breaking or coming off, which might allow the engine to run away, and as it was my intention to start the engine and allow it to go with practically no attention during the run, I provided a little switch in the battery circuit, which switch is clamped to one of the bearings of the engine, and there is a small centrifugal device, which on a speed of 260 to 270 being reached will be thrown out and knock the switch open, thus cutting off the igniting current. I have caused the engine to run away on two or three occasions and tested the device. It works perfectly.

I suppose that you have been told by Mr. Priestman that our exhaust pipe is led underground in a mass of loose stone, and that on testing the engine with the free exhaust we find that it carries just the same load as it does when the exhaust is underground. The back pressure is insignificant, owing probably to the fact that our pit was carried into a loose gravel bank, which bank is many feet above water level, and forms practically, therefore, a sort of air sieve into which gases can be discharged with comparative freedom from back pressure. This rids us of the smell and noise of the exhaust.

We have not yet put in our storage batteries and are running the engine and dynamo directly for lighting. We run about five hours each evening and have been starting up the engine and leaving it running in the dark for hours together while supplying the light to the house. We can say, therefore, that outside of the starting and stopping it demands practically no attention and is automatic in all respects.

For cooling the cylinder we simply have a large tank in the attic of our building connected by two pipes, one at the top of the cylinder and the other at the bottom, and this gives us a vigorous water circulation, and at the same time secures for us a supply of warm water which can be used during the winter in the stable.

I may have transcended the limit of your inquiry, but I felt justified in doing so from the desire to have you know more fully than a mere statement of the convenience of the engine would give, how useful and valuable it is. If there are any points concerning it about which I can give you any further information I should be very happy to do so. I am,

Very truly yours,

[SIGNED] ELIHU THOMSON.

For Pumping.—Mr. Coxe writes me:

(Copy.)

CROSS CREEK COLLIERIES, COXE BROS. & CO.

DRIFTON P. O., LUZERNE CO., PA., October 25, 1892.

Coleman Sellers, Esq., 3301 Baring Street, Philadelphia, Pa.

DEAR SIR:—Your letter is received.

We have had the Priestman oil engine working in our No. 1 Mine, at Drifton, for nine months. It was put in the mine on February 1st, and ran nicely until February 20th, when we had some trouble caused by the gas failing to ignite properly. At our request the Priestman Company sent a man to examine it. He came on the 26th of February and found the oil passage to governor blocked with soot and some fine particles in the valve of the air pump. From this time until March 14th it ran very well, but from this time until the middle of April we had considerable trouble to keep the oil pipe open, and the spray-maker would continually block with soot or lamp-black, and the engine would run only for a short time, one hour or less, and at last it got so that it would not run at all. We took out the piston and found the piston rings and the back of cylinder entirely blocked with soot. After we had cleaned these, we put them back and started up again. We ran for about a week, and then experienced the same trouble as before. We took it apart and cleaned the piston rings and back of cylinder as well as the oil pipe and spray-maker. The engine then started off and ran very well. At this time we got the water down so as to open the air shaft of the mine, thereby giving us plenty of air to work the pump, and from that time to this we have had no trouble; except about one week ago, when, in consequence of a change being made in the air course in the mine, we had trouble for a short time. We are satisfied that had the pump had a full supply of air from the start we would have had no trouble.

It seems to us that this is an important point to remember when putting a pump into a confined place where it may exhaust into the same atmosphere in which it works (of course, this could not occur in an open space). As the pump is adjusted to do its work with a supply of normal air, when the quantity of oxygen is decreased and the quantity of carbonic acid is increased, perfect combustion cannot take place. Some of the particles of carbon in the oil being unconsumed, deposit themselves as soot or lamp-black in the various parts of the engine. In our case, in consequence of the water having been pumped out, the bottom of the air shaft (which was closed by the water) was opened and a good current of air was established when the whole difficulty disappeared. For the last five months, except when we were changing the air passage in the mine a week ago, the engine has worked very satisfactorily.

The engine seems to run very well when the air supply is pure, but when the air is not pure you may have trouble. This, of course, does not apply to an engine placed outside.

The engine we have is pumping water. It is connected by means of a friction clutch to a pinion which gears into a large wheel; on the shaft of the large wheel, there is a small pinion which gears into another large wheel on which is a crank which drives the pump.

It is very important to have good supply of fresh air to the pump, as we find that in every case where our ventilation is for any reason defective, the pump shows it at once.

We do not run the pump steadily as it depends upon the amount of water that the mine is making. When running steady we use from four to five quarts* of kerosene per hour. It was a twelve-inch cylinder and twenty-four-inch stroke and raises the water a little less than ninety feet. Our object in getting the engine was to have a pump that we could move about, as the workings would gradually deepen and extend, and the pump could not always be kept in the same place. For this class of work we find it very satisfactory.

I enclose you a blue print of the exact arragements.

Hoping this will give you the desired information, I am,

Yours truly,

[SIGNED] ECKLEY B. COXE.

For Cotton Ginning.—Mr. M. Wilkins writes me:

(Copy.)

FAUNSDALE, MARENGO CO., Ala., December 5, 1892.

Dr. Coleman Sellers, Philadelphia, Pa.:

DEAR SIR:—Your favor of November 30th to hand this day, and in giving you my experience with the Priestman engine, will say I have used it to drive my cotton gin, gin feeder, condenser and cleaner, and find it superior to any power I have seen for this purpose.

In ginning we need a very steady, smooth power, as some parts of our machinery are driven at a high rate of speed, and any jerking or racing injures the fibre as well as the machines. Its fine governing qualities fill another emergency for us, in enabling us to throw the load off at any time with impunity, as sometimes we find sticks, stones, pieces of iron and the like amongst our gin saws, which requires an instant stopping of the gin.

I had occasion to test it severely a few days since, finding a bonnet lost by one of my pickers had gotten tangled in the gin feeder, while the engine (alone down-stairs) was driving a very heavy load, I threw the clutch pulley out in a second and rushed down-stairs to see the result. I soon found out the gin needed my attention, as the engine was taking care of itself splendidly.

The igniting device I find absolutely perfect, having never failed in a single instance when properly adjusted. I was instructed by the builders to carry the exhaust about twenty or thirty feet up, but not being convenient to do so, I put it out laterally about three feet from ground level, and have experienced no trouble at all from disagreeable smell.

* This is a nine effective horse-power engine.

Having no stream to depend upon for water to circulate around the cylinder, I mounted twenty barrels and connected them with one-inch nipples six inches long, which gives me enough water to make a steady ten hours' run, and by next morning water is all cold again.

I have experienced no trouble in regard to the piston which I feared would not lubricate as it should, also find the bearings in good shape after as long as six hours' runs, showing the lubricating arrangement in that line was perfect.

My pump let down once but I found I was drawing out of the barrels without a screen over the suction pipe and a small chip got in the pump valve, which I removed and had no further trouble. By adjusting the thumb screw on the relief valve I have regulated the air pressure on the oil tank to a nicety.

I have never figured accurately on consumption of oil, but don't think I have ever used over one pint per hour to the horse-power, if that. I am so pleased at the idea of being rid of the treacherous steam boiler and the expensive handling of wood or coal to keep up steam that I am very willing to allow the engine one quart per hour.

I usually heat the mixer about twenty minutes, start the engine and let it make about a dozen revolutions then throw on the load, and leave it.

I handle my engine with ordinary field hands who never had any experi ence with other motors than hay burners (mules) and think I have a simple, safe, economical and reliable power.

I may have somewhat over-reached the limit of your request but trust the humble opinion I have expressed may cause others to take hold of the Priestman engine, and be as much pleased with it as I am. If I can be of any further service I am yours to command.

Your obedient servant,

[SIGNED] M. WILKINS.

MANGANESE STEEL.

By Henry M. Howe.

[*A lecture delivered before the Franklin Institute, February 20, 1892.*]

Mr. Howe was introduced by the Secretary of the Institute, and spoke as follows:

Members of the Institute, Ladies and Gentlemen:

Manganese steel is an alloy of iron with from say three to twenty per cent. of manganese. Certain varieties of it are extremely ductile, and yet very strong and extremely and unchangeably hard. This combination of simultaneous hardness and ductility is, I believe, quite unique.

Common or carbon steel may be extremely ductile in its annealed state, and extremely hard in its hardened state; while the self-hardening steels are nearly unchangeably hard, but always brittle. I know of no substance, organic or inorganic, except manganese steel, which is at one and the same time both hard and ductile. Indeed, hardness and brittleness usually go hand-in-hand to such a degree that the word "hard" is often carelessly used in the sense of "brittle." And I believe that not a few of us have, by association, come to regard hardness and ductility as in some way absolutely incompatible.

Manganese steel was discovered and patented by Robert Hadfield, and to him and his son we owe most of our information about it.

Manganese steel conducts both heat and electricity extremely badly, and is but faintly magnetizable.

The influence of manganese on the properties of the alloy is probably profoundly influenced by that of the carbon, which at present unavoidably increases with the manganese. We cannot now make thirteen per cent. manganese steel with much less than one per cent. of carbon; and we can only guess what its properties would be without this carbon.

Let us consider some of the properties to which I have thus referred, and later the preparation and the uses, actual and anticipated, of this remarkable material.

Its properties vary strikingly with the proportion of manganese which it contains, and with the treatment it has undergone. Except where the contrary is explicitly stated, I confine myself to-night to the alloy containing about thirteen per cent. of manganese, in its ductile or "water-toughened" state.

Let us first consider the tensile properties of manganese steel, its tensile strength, both elastic and ultimate, and the ductility which a bar of it displays when torn apart longitudinally or tensilely, as in the most common form of tests for engineering and scientific purposes. The general worth or merit of any particular lot of iron or steel is usually measured by its combination of strength with ductility. I do not now speak of its fitness for this or that particular purpose, but of its general merit. The scientific investigator needs one set of qualities; the poet, a second; the statesman, a third. Nevertheless, there are common standards which we apply to all, as measuring their general merit as men.

In case of carbon steel, at one extreme we have metal of enormous strength, but so brittle and treacherous that the engineer dare not use it. At the other, we have metal of extraordinary ductility, but so weak as to be of little value for many purposes. So, in a rough way, we habitually regard that steel which has the greatest strength for given ductility, or that which is the most ductile for given strength, as the best.

The most common measure of ductility is the permanent elongation which a bar of the metal undergoes when it is pulled in two by direct longitudinal stress; and this elongation is habitually measured in percentages of the initial length of the bar tested. The combination, then, of tensile strength with the permanent elongation on tensile rupture, or in short of strength and elongation, is the standard by which I first ask you to judge the excellence of manganese steel.

In *Fig. 1*, I have represented this combination graphically for manganese steel, and for many of the best reported specimens of common or carbon steel. (To distinguish common steel from manganese steel, I shall speak of it in this lecture as carbon steel.) In this diagram the ordinates, or the vertical distances of the several spots from the horizontal axis, indicate the ductility as measured by the permanent elongation undergone by a given test-piece prior to rupture; the abscissæ, *i. e.*, the horizontal distances of the

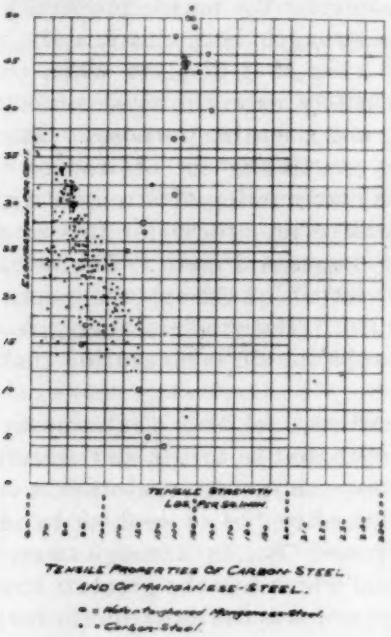


FIG. 1.

several spots from the vertical axis, indicate tensile strength. The little black spots represent the properties of carbon steel, and you note that they fall in a tolerably well-defined band, the elongation diminishing as the tensile strength increases.

Note, however, how greatly the manganese steel specimens excel those of carbon steel in their combination of strength with ductility. For a tensile strength of from 130,000 to 150,000 pounds per square inch, none of the car-

bon steels have more than sixteen per cent. of elongation; while many of the manganese steels of this strength have an elongation of forty-five per cent., and some even of fifty per cent.*

But I think that this combination, which we have been considering, ultimate strength with ductility, is by no means so good a measure of general merit as the combination of ductility with elastic strength, or tensile strength within the limit of elasticity, or, as it is called, elastic limit. The elastic limit measures the power of the metal to resist stress without becoming permanently deformed. It is this, probably, rather than the ultimate tensile strength, that should, and some day will, determine the stress to which the material shall be exposed in practice. The ultimate strength of the material measures the stress, a single brief application of which will tear it apart; the elastic strength or elastic limit seems to measure the stress which, if indefinitely prolonged or repeated, will tear it apart. Now, if this be true, no matter how great the ultimate strength, we should not dare to expose materials indefinitely to a stress as great as their elastic limit.

Therefore, in *Fig. 2*, I have in like manner represented the combination of elastic limit with elongation in case of carbon steel, of manganese steel and of nickel steel. The little spots for carbon steel as before fall in a band running obliquely across the diagram, less clearly defined because of the smaller number of cases.

Two of the triangles, indicating nickel steel, lie well above the band of carbon steel; but even these are excelled by many of the circles which stand for manganese steel. [Since

* Since this lecture was delivered still more extraordinary combinations of strength and ductility in case of manganese steel have been reported. Mr. E. G. Spilsbury found in case of one specimen of wire a tensile strength of 400,000 pounds per square inch, with an elongation of thirty-three per cent. in six inches. An extraordinary case of ductility is reported by the same gentleman. Wire of No. 18 gauge, 0·046 inch in diameter, endured forty-eight twists in a length of six inches, and twenty-two bends. Its tensile strength was 155,000 pounds per square inch, and its elongation seventeen per cent. in six inches. These are picked results: in the first of them, an error is possible, though extremely improbable.

this lecture was read, other tests of nickel steel have come to my notice, in which this combination is as great as it is in the cases of manganese steel represented in *Fig. 2.*]

These comparisons may, however, give a false idea of the ductility of manganese steel. If two metals elongate in a like manner, the extent of their elongation may be a fair comparative measure of their ductility; not necessarily so, however, when their mode of elongating is unlike in kind. A bar of carbon steel habitually yields when pulled

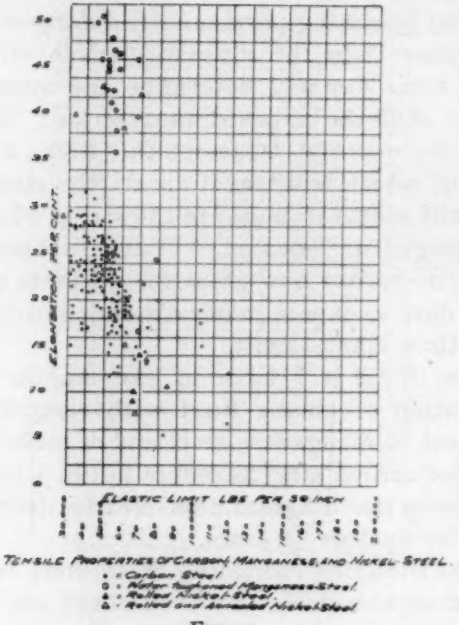


FIG. 2.

in two by "necking," contracting greatly just about the place where rupture occurs, as shown in *Fig. 3*, while a bar of manganese steel or of brass elongates far more uniformly over its whole length. For some purposes this uniform stretch may be better, for others worse, than the necking and localized stretch of carbon steel; suffice it here to point out that the two are different, and, therefore, not strictly comparable as a measure of ductility: and further that, thanks to the nearly uniform stretch of manganese steel over

the whole length of the test bar, its percentage of elongation may be held to give an exaggerated idea of the metal's true ductility or plasticity.

This granted, it yet remains that the metal is very ductile and has great strength, both elastic and ultimate.

This leads me to speak of a further peculiarity of the ductility of manganese steel, the difficulty with which cracks are propagated across it, *i. e.*, its non-fissility. This is illustrated by *Fig. 4*, in which are sketched the condition of one and the same test bar of manganese steel, in different stages of elongation under tensile stress. The stretching was inter-

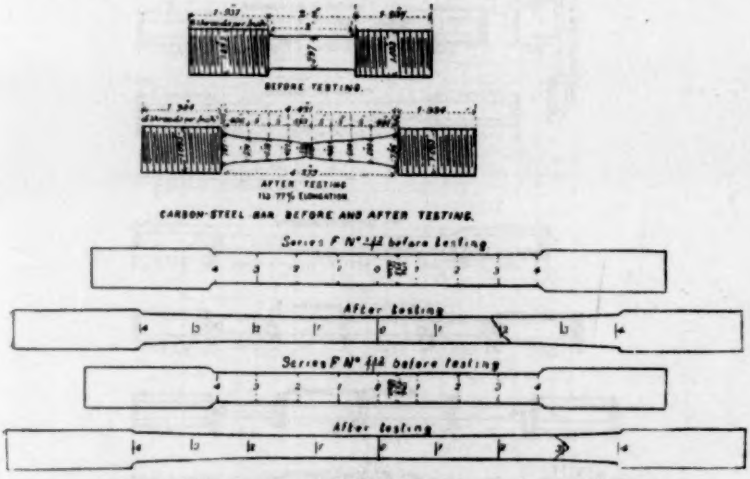


FIG. 3.—Manganese steel bar before and after tensile test.

rupted several times, and each time the test bar was water-toughened, *i. e.*, was heated to redness and then plunged in water. You will note, first, the uniform stretch over the whole length of the test-piece, in marked contrast to the necking of carbon steel shown in *Fig. 3*. Next you will notice three rough diamond-shaped figures in each of the lower three sketches. These are deep holes, unexpectedly resulting from the stretching of very light prick-punch marks; one of them is more than one-sixteenth inch deep, and one-fourth inch across. That so hard a material should tear in this way is most surprising. In one case daylight could be seen

through a test-bar while it was still enduring a tensile stress of over 110,000 pounds per square inch.

So in testing manganese-steel knuckles for automatic car-couplers, by an impact or drop test, it has been noted that, after the metal has begun to crack, it endures a surprising number of blows before breaking.

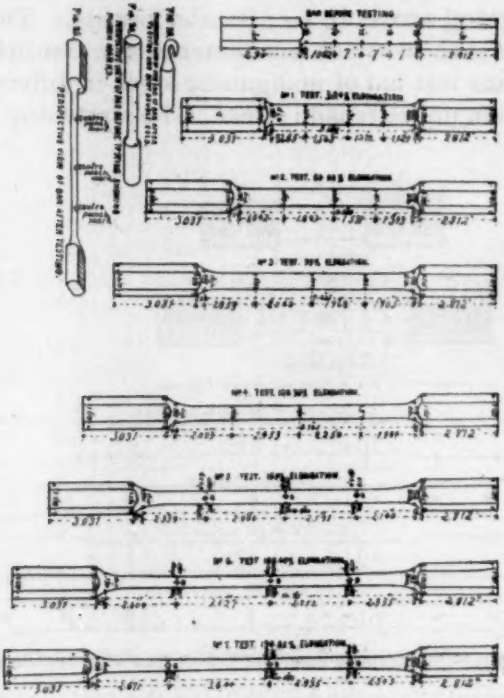
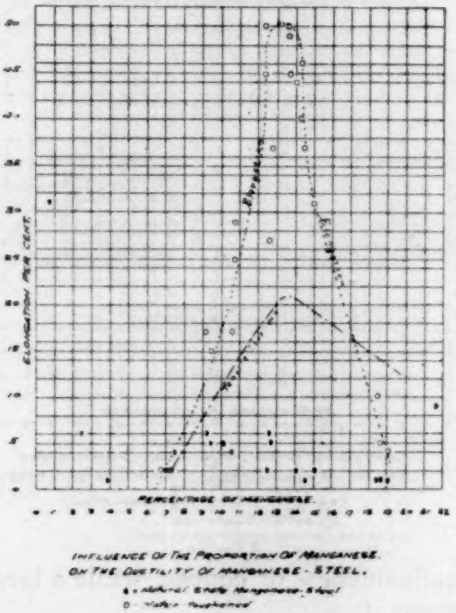


FIG. 4. Appearance of a single test-bar of manganese steel, before and after repeated stretching, each followed by water-toughening.

The way in which the tensile strength, and more especially the ductility of manganese steel, vary as the percentage of manganese increases, is very striking. As the manganese rises, the ductility at first diminishes very suddenly. It has long been believed that the presence of 1·5 per cent. of manganese made common carbon steel brittle. As early as 1877 a case came to my notice in which, by an error, a lot of rail steel which should have contained

about one per cent. of manganese, actually contained about 1·5 per cent., its composition being normal in other respects. It was dangerously brittle.

With further increase of manganese, the metal becomes more and more brittle. Manganese steel with from 4 to 6·5 per cent. of manganese, under certain special conditions, is so brittle that it can be pulverized with a hand hammer. But, as the manganese rises above seven per cent., the ductility of the water-toughened metal increases in a most striking



INFLUENCE OF THE PROPORTION OF MANGANESE ON THE DUCTILITY OF MANGANESE-STEEL.

FIG. 5.

way, till the manganese reaches about thirteen per cent. With further increase of manganese the ductility again diminishes, perhaps as fast as it had risen. This is illustrated graphically in *Fig. 5*, by a curve indicating roughly the elongation to be expected in water-toughened pieces.

Fig. 6 shows in like manner how the tensile strength of water-toughened manganese steel, very low when there is some seven per cent. of manganese present, rises rapidly, reaching a maximum when the manganese reaches some-

where about fourteen per cent., and again diminishing with further increase of manganese.

Returning again to *Fig. 5*, we note that the strength and ductility reach their maxima with about the same percentage of manganese.

But, though striking, the reversal of the effects of increments of manganese on the physical properties of the alloy, as its content of manganese rises above fourteen per cent., is by no means astonishing; for like cases are reported with other alloys. Thus a slight addition of zinc is reported to

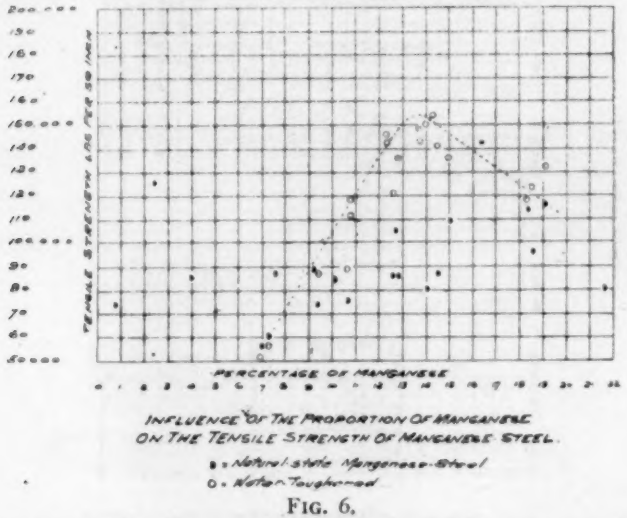

PERCENTAGE OF MANGANESE
INFLUENCE OF THE PROPORTION OF MANGANESE
ON THE TENSILE STRENGTH OF MANGANESE STEEL.
● = Natural state Manganese-Steel
○ = Water-Toughened

FIG. 6.

lessen the malleableness of copper, while a larger addition in turn increases it.

Fig. 7 compares the combination of strength and ductility of manganese steel with the same combination for nickel steel. The circles as before represent manganese steel, the triangles nickel steel. The combination as thus measured is seen to be on the whole much greater in manganese steel than in nickel steel. But this does not at all prove that manganese steel is better than nickel steel.

While manganese steel is intensely and astonishingly hard, considering its ductility, it is not as hard as chilled cast iron, nor as the hardest grades of carbon steel when

they are dead hardened, that is to say, brought to their very hardest state by quenching in water. Manganese steel containing some seven per cent. of manganese, indeed, is so hard that it can be used for cutting iron; and lathe tools made from it have been used successfully. But the thirteen per cent. manganese steel, with which we concern ourselves this evening, is far from hard enough for this purpose.

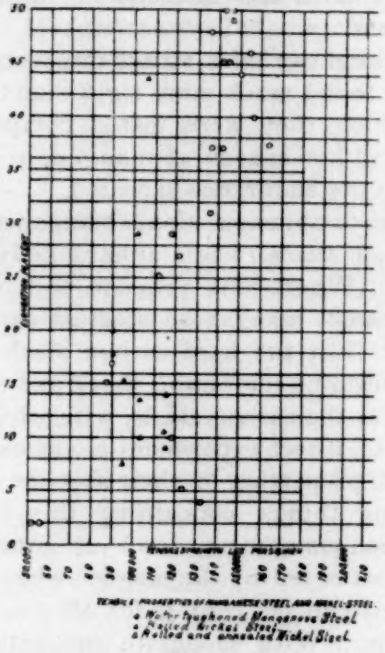


FIG. 7.

Moreover, the very fact that it is accompanied by great ductility, makes its hardness peculiar. We are accustomed to think of very hard bodies as incapable of being indented, as for instance by the blow of a hammer: but manganese steel can be thus indented. This, however, is a necessary consequence of its ductility. Most very hard bodies, such as glass, hardened steel, or chilled cast iron, if they receive a blow which passes their compressive elastic limit, simply break or crack; that is because they are not ductile; they cannot yield. Manganese steel, however, on receiving such

a blow simply yields. Within its elastic limit it behaves under blows like other hard substances. Let the blow exceed the elastic limit, and manganese steel yields where the others break.

I am hardly prepared to give a clear account of its rigidity. Under some conditions it has shown itself very rigid; under others it has not. As yet I cannot point out with confidence the conditions which make it rigid in some cases, but not in others.

Manganese steel car axles, struck transversely by a heavy ram, have been found much more rigid than those of carbon steel, with which they were tested competitively. Yet stamp shoes and horseshoes of manganese steel have not thus far shown the endurance expected.

In resistance to abrasion alone, manganese steel excels the hard carbon steels (when unhardened) and, *a fortiori*, the soft steels. Where both abrasion and repeated shocks are to be resisted, manganese steel is certainly far less liable to break than the hard carbon steels; but whether, under new conditions combining shock and abrasion, it will prove as rigid as the carbon steels, with which it will then have to compete, direct experiment alone can tell.

Its magnetic properties, or their absence, are among the most surprising things concerning this surprising substance. While manganese steel of nine per cent. of manganese is attracted by the magnet when finely divided, yet that of thirteen per cent. is for all practical purposes unmagnetizable. With moderate magnetizing force, its susceptibility to magnetic influences is, according to Ewing, only about $\frac{1}{8000}$ that of soft iron. "No magnetizing force to which the metal is likely to be subjected in any of its practical applications will produce more than the most infinitesimal degree of magnetization." Yet with enormous magnetizing force, for instance of 10,000 C. G. S. units, it is possible to magnetize manganese steel very considerably.

If its resistance to magnetization is great, so is its resistance to the passage of heat and of electricity. Of each it is a very poor conductor.

Fig. 8, from determinations kindly made by the Thom-

son-Houston Electric Company, of Lynn, Mass., comparing the electric resistance of manganese steel with that of copper and of soft iron at different temperatures, shows that the resistance of manganese steel at 0° C. is nearly seven times that of soft iron, and is very much less affected by changes of temperature than the resistance of either soft iron or copper. Its resistance is about double that of platinoid, and thrice that of German silver.

Preparation.—Manganese steel of the class that I am describing to-night is made by stirring together the molten,

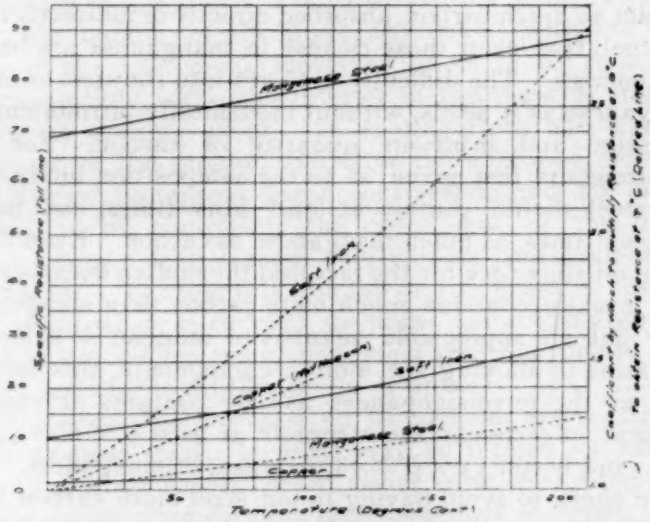


FIG. 8. Electrical resistance of manganese steel, copper and iron.

thoroughly decarburized product of the open-hearth or Bessemer process and molten, highly heated, rich ferro-manganese. Care must be taken to avoid loss of manganese, and to keep the proportion of carbon down. The product should have not less than eleven per cent. of manganese, and not more than 1·25 per cent. of carbon. If we can give it as much as thirteen per cent. of manganese and less than one per cent. of carbon, it will be better for most purposes. So high a ratio of manganese to carbon can be had only through great care.

The high cost of metallic manganese puts it beyond our reach as a material for making manganese steel. The only present available source of manganese for this purpose is the carburetted alloy of iron and manganese called ferro-manganese, made in the iron blast furnace from ores of manganese. It usually contains about eighty per cent. of manganese, six per cent. of carbon and thirteen per cent. of iron, though occasionally the proportion of manganese rises to beyond eighty-seven per cent., with as little as seven per cent. of iron.

These crude products of the blast furnace necessarily contain so much carbon, absorbed directly or indirectly from the fuel, that even those richest in manganese are barely rich enough. The difficulty is to get into the steel as much manganese as it needs, without incidentally introducing an excessive and injurious quantity of carbon. For the requirements just given as to the composition imply that the steel should contain at least nine times, and better thirteen times, as much manganese as carbon. Even if we make no allowance for the fact that the molten decarburized iron usually contains much more carbon than manganese, and that an appreciable quantity of manganese is lost by oxidation in alloying the molten components, this implies that, as the ferro-manganese usually contains at least six per cent. of carbon, it must contain at least $9 \times 6 = 54$ per cent., and better $13 \times 6 = 78$ per cent., of manganese.

In short, to avoid having in our steel more carbon than is desirable, we must use a ferro-manganese as rich as possible in manganese, and alloy it with iron containing as little carbon as possible.

Such iron is that made either in the Bessemer process or in the open-hearth process, by thoroughly decarburizing cast iron. In making merchantable steel (other than manganese steel) by either of these processes, a little carbon or manganese, or both, must actually be added to this thoroughly decarburized iron, in order to make it malleable, for reasons which we need not here consider. But in making manganese steel we deal with simply this thoroughly decarburized iron.

The loss of manganese in preparing manganese steel, according to Hadfield, equals about 0·50 per cent. of the total weight of the decarburized iron plus ferro-manganese used; *e. g.*, if the charge should by calculation, and without allowing for loss of manganese, contain 13·5 per cent. of manganese, it will actually contain about thirteen per cent.

After carefully mixing the molten iron and ferro-manganese, they are poured into suitable moulds of iron or sand, as the case may be. Large ingots are habitually cast in iron moulds; and here an important precaution must be observed.

Thanks to the slowness with which this metal conducts heat, the outside of the ingot, in contact with the cold walls of the iron mould, cools so far as to be rigid and incompressible, while the interior of the ingot is still far above its melting point. In cooling from this exalted temperature the molten, and later the solidified metal of the interior, undergoes great contraction, and no longer suffices to fill completely the outer shell of the ingot. Hence arises a deep vacuous cavity in its centre, known as the "pipe." To meet this, the top of the ingot is covered with charcoal, so as to keep its upper surface molten, and fresh lots of molten manganese steel are from time to time added, in order to fill this cavity or pipe.

Treatment.—We now pass on to consider the treatment of manganese steel. In what may be termed its natural state, *i. e.*, when slowly cooled either from the initial heat of casting or after forging, *manganese steel is brittle.* The ductility which gives it value is obtained only by sudden cooling from a high temperature, *e. g.*, by plunging it while red-hot into cold water.

We are all familiar with the remarkable effect of suddenly cooling common steel, as for instance by plunging it while red-hot into water or oil; we all know how this hardens the metal, makes it relatively brittle, and, if judiciously performed, strengthens it. (In speaking of hardness, I invariably refer to the hardness proper, the resistance to indentation and abrasion.)

But the effects of sudden cooling on manganese steel and

on carbon steel are in some respects very unlike. The tensile strength and elastic limit of both may, indeed, be greatly raised by sudden cooling; but even here a difference is noticeable. For while sudden cooling, even if very sudden, indeed violent, increases the strength of manganese steel greatly, the rate and conditions of cooling must, in case of carbon steel, be carefully regulated if great strength be sought; and indeed very sudden cooling may actually greatly weaken carbon steel, and require a subsequent tempering; that is to say, mitigating, or letting down.

When, however, we turn to the effects of sudden cooling on the hardness proper and the ductility of these two substances, carbon steel and manganese steel, we find a most marked difference. Sudden cooling hardens carbon steel greatly, and may make it so hard that it scratches glass readily; if it affects the hardness proper of manganese steel at all, its effect is so slight as to be detected only by delicate tests. Sudden cooling tends to lessen, and if very sudden may quite destroy the ductility of carbon steel, leaving the metal as incapable of receiving permanent set as glass is. Yet the same sudden cooling increases the ductility of manganese steel astonishingly.

Fig. 5 illustrates graphically the influence of sudden cooling on the ductility of manganese steel. Here the properties of manganese steel in its natural state are indicated by black semi-circles, the circles indicating the properties of the metal when suddenly cooled by quenching in water, or, as it is called, "water toughened." We see that, while the elongation of the metal in its natural state is usually below five per cent., that of the water-toughened material rises occasionally to fifty per cent.

Fig. 6 illustrates in like manner the influence of sudden cooling or water toughening on the tensile strength. We note that, while the tensile strength of the metal in its natural state, as indicated by the black semi-circles, rarely rises above 100,000 pounds per square inch, that of the water-toughened metal, indicated by the circles, is usually above 110,000 pounds, and rises to even above 150,000 pounds per square inch.

[*To be continued.*]

MAXIMUM STRESSES FROM MOVING SINGLE LOADS IN THE MEMBERS OF THREE-HINGED ARCHES.

By Emrick A. Werner.

[*Concluded from p. 50.*]

D_{III} *min.:*

Maximum line $g_m = 75{\cdot}0$

Minimum span = space from (*o*) to (30)

c being positive and $\left(\frac{l}{2} - g_m\right) = o$

$$\frac{d\,D}{d\,g} = 0{\cdot}20\ W_I - w$$

W_I = load on left side of arch.

First wheel 112·0 from Abutment *B*, second tender wheel 1·0 from Abutment *A*.

$$D_{III}\ min. = \left(\frac{M}{h}\right)_{45} - \left(\frac{M}{h}\right)_{30} = -\ 558 \div 17{\cdot}5 = -\ 31{,}900$$

D_{IV} *min.:*

Maximum line = 93·75

Maximum span = space from (*o*) to (45)

c being positive and $\left(\frac{l}{2} - g_m\right) = o$

$$\frac{d\,D}{d\,g} = +\ 0{\cdot}16\ W_I - w$$

W_I = loading on left side of arch.

$$D_{IV} = \left(\frac{M}{h}\right)_6 - \left(\frac{M}{h}\right)_{45} = -\ 907 \div 17{\cdot}5 = -\ 51{,}800$$

$$D_V = -\left(\frac{M}{h}\right)_{60} = +\ 62{,}100$$

Vertical stresses P in the posts.

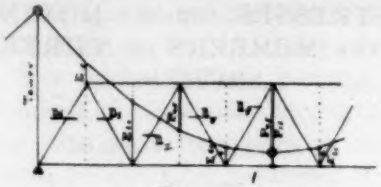


FIG. 33.

P_{75}.—

P_{75} is a maximum and minimum with D_V hence:

$$P_{75}\ max. = \left(\frac{M}{h}\right)_{80} \times tan\ a = 62{\cdot}600\ \frac{17{\cdot}5}{15} + 73{,}200$$

compression.

$$P_{75}\ min. = \left(\frac{M}{h}\right)_{80} \times tan\ a = 62{\cdot}100 \times \frac{17{\cdot}5}{15} = 72{,}600$$

tension.

P_{45}.—see *Fig. 33.*

Considering P_{45} as consisting of two coinciding posts, P left and P right, each acted upon by one diagonal, and remembering that in defining P maximum and P minimum that end of the post must be selected, which takes up no moving load, we have:

$$P_{15} = \pm (D_{IV} \pm D_{III})\ tan\ a$$

Barring out the cases in which both diagonals are in tension, from which we know the stress will be smaller than that from one diagonal, the above equation becomes:

$$P_{15} = \pm (D_{IV} - D_{III})$$

$(D_{IV} - D_{III})$ will be a maximum or minimum, when one of the D's, as the case may be, is equal to zero; $-D_{IV}$ and D_{III} represent the following divisions of W_1 and W_2 (see *Fig. 34*).

Developing we find:

$$h\ D_{IV} = -0{\cdot}16\ W_1 g_1 + W_2 (15 - 0{\cdot}16\ g_2) + 0{\cdot}04\ W_3 g_3$$

$$h\ D_{III} = -0{\cdot}20\ W_1' g_1' + W_2' (15 - 0{\cdot}20 g_2')$$

$$P_{45} = \pm \frac{tan\ a}{h} \left[-0{\cdot}16\ W_1 g_1 + W_2 (15 - 0{\cdot}16\ g_2) + \right.$$
$$\left. + 0{\cdot}04\ W_3 g_3 + 0{\cdot}20\ W_1' g_1 - W_2' (15 - 0{\cdot}20\ g_2') \right]$$

and

$$\frac{dP}{dg} = \pm [0.16\,(W_1 + w) + 0.16\,W_2 + 0.04\,W_3 - w - \\ - 0.20\,(W_1' + w') - 0.20\,W_2' + w']$$

$$W_1 + w + W_2 = W_1' + w' + W_2' = W_1$$

$$\frac{dP}{dg} = \pm [0.04\,(W_3 - W_1) - (w - w')]$$

Making $b = o$ in the above general equation of P_{45}, we find:

$$g_m = 93.75\ P \text{ left} = \frac{15}{0.16}$$

$$g_m' = 75.0\ \ P \text{ right} = \frac{15}{0.20}$$

both maximum lines run to the top hinge, and $(g_m - a)$ reaches from (45) to (75) and from (60) to (75). Hence the signs of b and b' be positive, and the signs of the coëfficients, as shown in *Fig. 34*.

FIG. 34.

Maximum P_{45}.—

With these signs we find the maximum span of P_{45} in taking those parts of the truss corresponding to positive values of the *combined* coëfficients of P right (D_{IV}) and P left (D_{III}).

In our case the combined action of a and $a' = 0.20 - - 0.16 = 0.04$ will be positive from (o) to (30). From point (30) to point (60) the coëfficients are negative, from (60) to (75) the combined action of c and c' is $(15 - 0.16\ g_2) - - (15 - 0.20\ g_2)$. This difference gives for $g_2 = 60$ the value $+ 2.4$, for $g_2 = 75$ the value $+ 3$. The combined action of c and c' is thus positive. From (75) to (150) c is positive.

We have thus for the maximum span the following diagram:

FIG. 35.

and the condition of P_{45} max. will be $(w - w')$ being equal to zero.

$$\left[\begin{array}{l} \dfrac{d\,P}{d\,g} = W_3 - W_1 \\ \\ D_{IV} = o \end{array}\right.$$

W_1 = load on left side of arch.

We find the corresponding position

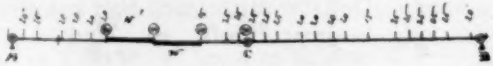


FIG. 36.

in shifting the position answering $W_3 - W_1$ until D_{IV} becomes zero.

From this position follows:

P_{45} *max.* = 50,100 compression.

Minimum P_{45}.—

The minimum span of P_{45} embraces those parts of the truss corresponding to negative values of the combined coëfficients $a\ b\ c\ \beta$, as shown in *Fig. 37*,

FIG. 37.

and the conditions of P_{45} min. are:

$$\left[\begin{array}{l} \dfrac{d\,P}{d\,g} = w - w' \\ \\ D_{III} = o \end{array}\right.$$

We find accordingly

FIG. 38.

giving P_{45} minimum = 60,500 pounds tension.

Stresses in the hangers.—

The maximum and minimum corresponds to the maxi-

mum and minimum loading of the floor beam. The minimum is equal to zero. The condition of maximum is:

FIG. 39.

$$\frac{d\,p}{d\,g} = 2\,W_1 - W$$

whence

$$p = \frac{(R_2 - R_1) - (R_3 - R_2)}{\Delta_x} = 82{,}500 \text{ pounds.}$$

With these values we find now the stresses in the members themselves.

Stresses in the cable.—

$$H \div \cos \mu$$

Maximum:

First panel 467,000 pounds.

Second panel 434,000

Third panel 408,000

Fourth panel 390,000

Fifth panel 380,000

Minimum = o

Vertical stresses in suspension rods.—

$$E_x = H\,(\tan \mu_{x+\Delta x} - \tan \mu_x)$$

Maximum = 60,000

Minimum = o

Stresses in the chords.—

$$C_x = \left(\frac{M}{h}\right)_x$$

From the sign of D must be found the direction of the chord stresses.

This is done with triangular trusses in the easiest way, in introducing the diagonals as diagonals in tension in a truss with similar rectangular panel division, and in trans-

ferring the chord pieces of those panels, in which the diagonals have the same position in both trusses, into the triangular truss.

We find in this way

Maxima (positive moments):

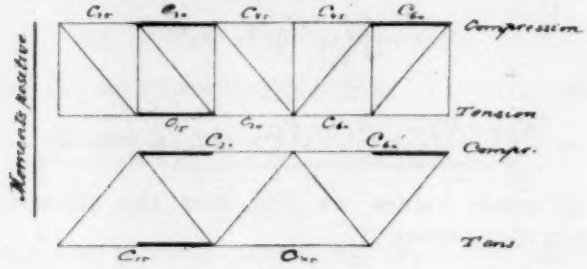


FIG. 40.

Top Chord:

Second and third panel 108,200

Fourth and fifth panel 62,600

Bottom Chord:

First and second panel 79,300

Third and fourth panel 103,900 (tension)

Minima (negative moments):

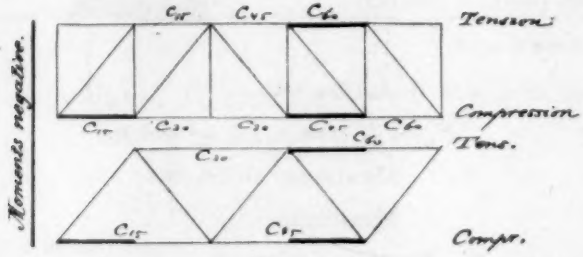


FIG. 41.

Top Chord:

Second and third panel 104,000 tension.

Fourth and fifth panel 62,100 tension.

Bottom Chord:

First and second panel 71,500 compression.

Third and fourth panel 99,700 compression.

Stresses in the diagonals.—

$$D \div \cos a = D \div 0{\cdot}651$$

Calculate as for truss with square panels and reverse the stress in the reversed diagonals.

Maxima:

First panel	—	122,000
Second panel	+	71,600
Third panel	—	48,900
Fourth panel	+	75,300
Fifth panel	+	96,200

Minima:

First panel	+	109,700
Second panel	—	55,500
Third panel	+	49,000
Fourth panel	—	79,600
Fifth panel	—	95,400

Vertical stress in the posts.—

P_{45} = 50,100 compression.
60,500 tension.

P_{75} = 73,200 compression.
72,600 tension.

Hangers:

82,500 pounds.

DEAD LOAD.

As in the first example (upright arch) the dead load is assumed at 26,000 pounds per panel point. As H, R and M have the same value in both examples, we have,

Stress in the cable = stress in the lower chord of example *I*.

Stress in the suspension rods.—

$$E = H(\tan \mu_{x+\Delta x} - \tan \mu_x) - p' = 0{\cdot}16\, H - p' =$$
$$= 26{,}000 - 8{,}000 = 18{,}000 \text{ pounds.}$$

Stress in the chords = *o*

Stress in the diagonals = *o*

Stress in the posts:

$$P_{75} = -2{,}000 \text{ pounds.}$$

$$P_{45} = -4{,}000 \text{ pounds.}$$

Stress in the hangers = 14,000 pounds.

With these figures the following strain sheet is computed:

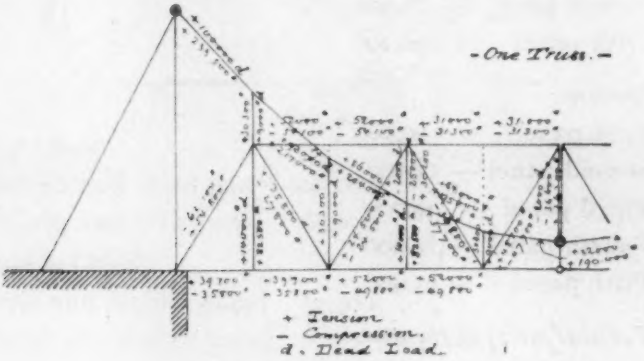


FIG. 42.

The examples are selected merely with the intention of showing in the smallest space all the casualties of actual figuring. They give in no way data for comparing arched trusses and trusses with vertical reactions only.

The calculations are given in full length with the possible checks. In actual figuring much of this work can be avoided.

PROCEEDINGS

OF THE

CHEMICAL SECTION

OF THE

FRANKLIN INSTITUTE.

[*Stated meeting held Tuesday, January 17, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, January 17, 1893.

Dr. Wm. H. Greene, President, in the chair.

Dr. Wahl nominated Mr. Joseph Richards, 1802 Catharine Street, Philadelphia, and Mr. Jesse Jones, care of Messrs. Wm. Cramp & Sons, corner York and Thompson Streets, Philadelphia, for full membership in the Section. After action by the Committee on Admissions these gentlemen were declared elected.

Dr. Greene, as chairman of the committee appointed to consider the subject of securing additional papers for the meetings of the Section, made the following report:

"The committee to which was referred the suggestions of Dr. Day that, at stated intervals, reports should be prepared for the Chemical Section on the progress in certain lines of Chemical investigation, respectfully recommends:

"That at every alternate meeting of the Section a conference be given by one of the members, covering the development of some point that may be of general interest to the Section;

"That a committee of three be appointed to serve during the ensuing year for the purpose of securing members or others to give at least five such conferences.

"On inquiry, the committee has found that a number of members are willing to undertake the preparation and presentation to the Section of informal lectures on new developments of the science, and believe that such conferences and general discussion of the subjects considered cannot fail to be of interest to the members, and to increase the attendance at the meetings."

In accordance with this report the President named as members of the committee for 1893, Dr. Wahl, Chairman, Dr. Keller and the Secretary.

The same members as for last year were continued on the Committee on Admissions.

The President appointed Mr. Haines and Dr. Keller members of the Finance Committee.

Dr. Wahl suggested that the Chemical Section might, with advantage to the Institute, exercise the function of securing the lectures on chemical subjects in the general course of lectures annually given by the Institute. He further recommended that the suggestion be left for the present, in order to give time for due consideration by the members with a view of taking official action upon it later in the year.

Dr. Greene then read a highly interesting paper, for himself and Dr. Wahl, on "A New Process for the Production of Manganese on the Commercial Scale."

The paper was referred for publication.

After an animated discussion, partaken in by many of the members present, the Section adjourned. WM. C. DAY, *Secretary.*

PROCEEDINGS

OF THE

ELECTRICAL SECTION

OF THE

FRANKLIN INSTITUTE.

[*Stated meeting, held Tuesday, December 27, 1892.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 27, 1892.

Mr. Elmer G. Willyoung, President, in the chair.

Present, sixteen members and visitors.

The minutes of the previous meeting were read and approved.

Two nominations to membership were referred to the Committee on Admissions. The committee reported two elections since last meeting.

The following were elected officers for 1893:

President—Mr. Elmer G. Willyoung.
Vice-Presidents—Prof. Edwin J. Houston and Mr. C. W. Pike.
Secretary and Treasurer—Prof. L. F. Rondinella.
Conservator—Dr. Wm. H. Wahl.

Mr. Edwin F. Northrup read a paper on "Some Principles that must be Observed in the Construction of a good Closed-circuit Battery and some new Portable Dry Cells in which they are Applied." (First paper.) Referred for publication.

The chair called attention to the desirability of full discussion upon papers, and the importance of members hearing papers when read or receiving an abstract beforehand, if possible.

It was moved and carried that the Committee on Papers be authorized to send out abstracts of forthcoming communications with the meeting notices, whenever possible.

Adjourned.

L. F. RONDINELA, *Secretary.*

PROCEEDINGS.

[*Stated meeting, held Tuesday, January 24, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, January 24, 1893.

Mr. E. G. Willyoung, President, in the chair.

Present, thirteen members and visitors.

The minutes of the previous meeting were read and approved.

The Secretary and Treasurer presented his annual report for 1892, which showed the Section to be in an active and prosperous condition. It was accepted and referred for publication.

The Treasurer reported the cash balance in the treasury, and presented bills for printing and clerical work, which were approved and ordered paid.

The Committee on Admissions reported two elections to membership since last meeting.

Mr. R. C. Hindley's resignation of active membership was presented and accepted.

A communication was read from the Secretary of the Institute, desiring information as to whether the Section would wish to publish an annual volume of its proceedings for this and future years, as the matter would all be printed in the monthly *Journal of the Institute*, and sent gratuitously to each member. Upon motion, the President and Secretary were appointed a committee to confer with the Publication Committee upon this subject.

On account of ill health from over-work, Prof. Rondinella regretfully offered his resignation as Secretary and Treasurer of the Section, to take effect upon the election of his successor at the February meeting. It was accepted with regret.

Mr. Edwin F. Northrup read the second part of his paper on "Some Principles that must be Applied in the Construction of a good Closed-circuit Battery, and some new Portable Dry Cells in which these Principles are Applied." Referred for publication. The paper gave the results of a most complete series of experiments, and was discussed by Messrs. Stradling, Willyoung, Billberg and Winand.

Prof. Geo. F. Stradling's paper, on "The Migration of the Ions," was deferred until next meeting.

Upon motion a committee of three was appointed to prepare and present a review of each month's electrical progress at the regular meetings of the Section.

The meeting then adjourned.

L. F. RONDINELLA, *Secretary.*

SOME NEW APPARATUS FOR THE MOST EXACT COMPARISON AND ADJUSTMENT OF RESISTANCE STANDARDS AND THE DETERMINATION OF TEMPERATURE COËFFICIENTS.

BY ELMER G. WILLYOUNG.

[*Read at the stated meeting, held November 22, 1892.*]

A little over a year ago I had the honor to present to the notice of the Section some general considerations with reference to the manufacture and adjustment of standard resistances.* During the course of the paper which I then read I exhibited and explained the operation of, to the Section, a piece of apparatus originally suggested to me by Prof. H. S. Carhart, of Michigan University,† and later modified by myself and intended for the very exact comparison and adjustment of standards and the determination of their temperature coëfficients. This apparatus was then and still is being used by Messrs. Queen & Co. as part of their equipment for the commercial doing of this work. This piece of apparatus I have not here to-night, but will sketch it upon the board later in order to bring its details clearly before us. I expressed myself, at that time, as believing it to be perfectly simple and easy to quickly adjust any single standard of resistance by the aid of this apparatus with a certain accuracy of $\frac{1}{100}$ per cent. Since the reading of that paper this method and apparatus have been in constant daily use in our laboratory, and my belief is its convenience and accuracy has been confirmed and strengthened. In the use of the apparatus we have, I

* "Resistance Standards: their Manufacture and Adjustment," *Journal of the Franklin Institute*, April, 1892.

† The first apparatus, made according to Prof. Carhart's design, was made by me either in 1887 or 1888, while I was still a student at the University. It is still in the laboratory there, and in constant use, and is, I am told, as good as ever.

think, at one time or another, been obliged to note every weak point in its theory or construction, and to provide such temporary means as might be obtainable for getting around difficulties as they arose. On a basis of an experience thus obtained I have recently designed and built an improved form of this apparatus, which is in every way greatly superior to the apparatus I then showed, and which I believe, from reports which I have received of the apparatus used at the leading laboratories of the world for this same purpose, is capable of giving closer comparisons, and of being used to obtain the value of a single standard to a higher degree of accuracy than any other arrangement of apparatus in the world; with this improved apparatus in the hands of a skilful observer, I consider it entirely

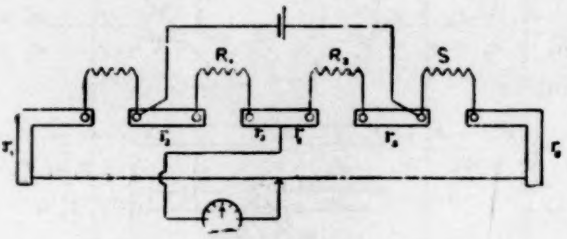


FIG. 1.

possible to determine the value of one coil in terms of another to an accuracy of $\frac{1}{1000}$ per cent. and even greater.

As the details of the arrangement and method are not fresh in the memories of most of you, I will hastily run over the general theory of the method, and of its application by means of the early apparatus, and then set forth the improvements which have been made and embodied in this newest form. Let *Fig. 1* represent, diagrammatically, the orthodox slide wire bridge in which X is the unknown resistance (nearly equal to the coil S), to be accurately measured in terms of S, and R_1 and R_2 are resistances roughly equal to one another and to S. The balance reading will then fall near the centre of the bridge. The heavy copper end straps are of resistances which may be designated by r_1 and r_6, the resistance of the other connectors by

r_2, r_3, r_4 and r_5, as shown. When a balance is obtained, we have

$$\frac{R_1 + r_2 + r_3}{R_2 + r_4 + r_5} = \frac{X + r_1 + x_1\rho}{S + r_6 + (L - x_1)\rho} \quad (1)$$

x_1 being the reading;

L being the whole length of the bridge wire;

ρ being the resistance of a single division of the bridge wire.

Reversing the position of X and S, and balancing again, we have

$$\frac{R_1 + r_2 + r_3}{R_2 + r_4 + r_5} = \frac{S + r_1 + x_2\rho}{x + r_6 + (L - x_2)\rho} \quad (2)$$

From (1) we have

$$\frac{R_1 + r_2 + r_3}{R_1 + R_2 + r_2 + r_3 + r_4 + r_5} = \frac{X + r_1 + x_1\rho}{X + S + r_1 + r_2 + L\rho} \quad (3)$$

and from (2)

$$\frac{R_1 + r_2 + r_3}{R_1 + R_2 + r_2 + r_3 + r_4 + r_5} = \frac{S + r_1 + x_2\rho}{X + S + r_1 + r_2 + L\rho} \quad (4)$$

$$\therefore \quad X + r_1 + x_1\rho = S + r_1 + x_2\rho \quad (5)$$

and

$$S - X = \rho(x_1 - x_2)$$

or

$$X = S - \rho(x_1 - x_2) \quad (6)$$

so that the unknown X differs from the standard S by exactly the resistance of the bridge wire over which the slider moves in changing from one position of balance to the other when the coils X and S are interchanged; we also see that the expression is entirely independent of the *length* of the bridge wire, and also of the resistance of the connecting coppers. We may, therefore, measure as small differences as we please by merely making the resistance of our bridge wire small enough.

I will now sketch the earlier apparatus, *Fig. 2*. This was a device for quickly and easily interchanging the two coils, X and S, of *Fig. 1*. Upon a suitable insulating base are

mounted a number of copper straps and plates as shown; these are so arranged as to place four coils in exactly the same relation to one another as in *Fig. 1.* The lettering upon the two figures is the same. The coils X and S have their terminals resting in mercury cups; the coils R_1 and R_2, being eliminated in the measurement, are simply fastened firmly into the binding posts. The galvanometer and battery circuits are as shown. In the

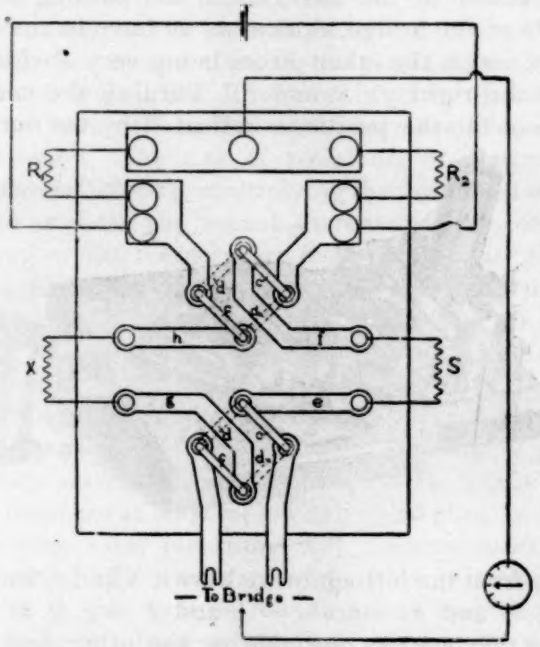


FIG. 2.

centre of the apparatus are seen two groups of mercury cups, each group forming a square; these groups are connected together, as shown, by the heavy copper rods C. By now running around the circuit from the left, clockwise, it will be seen that the order of the four coils is exactly the same as in *Fig. 1.* If, now, we alter the position of the heavy connecting rods C, to the position indicated by the dotted lines, the coils X and S will be interchanged as will be readily obvious by again following around the circuit. In

practice each *pair* of connectors is held in a little hard rubber platform, *C*, *Fig. 3*, so that but two movements are required to effect the change; being held loosely in the platform they will adjust themselves to the surface of the bottom of the cup, and thus make thoroughly good contacts. Inspection will show that this apparatus is a perfectly symmetrical arrangement, and that, consequently, the connector resistances need not be considered: thus, with the commutator rods as shown by the heavy lines, and passing around the circuit from the bridge, clockwise, we have in circuit on the left, *g*, *X* and *h*, the other pieces being very obviously *pairs*, and on the right *f*, *S* and *e*. Turning the commutator through 90° to the positions indicated by the dotted lines,

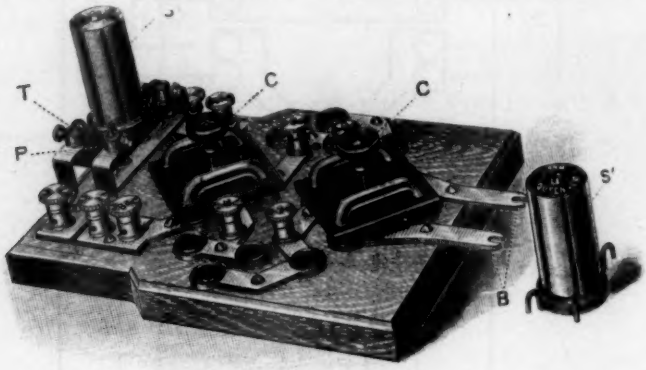


FIG. 3.

starting from the left again we have *e*, *S* and *f*, and from the *right* *g*, *X* and *h*; since $e = h$ and $f = g$, it is the same whether they are on one side or the other, and therefore only the resistances *X* and *S* have really been interchanged. To *use* this apparatus it is only necessary to insert the two slotted terminal straps into one of the gaps of an ordinary slide wire bridge. In the work which we have been doing we have been using a special form of slide bridge designed by myself, and having three wires, each a metre long, which can be thrown into multiple with one another if desired.

Having thus described the earlier form and arrangement of the apparatus I will now speak of its inconveniences and defects. The first one arises when we attempt to obtain

the value of the resistances of the bridge wire per unit division. This, of course, might be obtained by connecting the ends of the wire directly to a Wheatstone's bridge arrangement and obtaining its resistance by ordinary methods. The resistance, however, is necessarily very low, as we shall see from the following considerations: Suppose we have a standard ohm and a resistance of platinoid nearly equal to the ohm, whose temperature coëfficient we wish to exactly determine. We place our two coils in oil baths with both at (say) 15° C. and obtain a balance; we then carefully raise the temperature of the platinoid to (say) 30° C., and balance again. The difference, in terms of resistance of the bridge wire, will be the actual increase in resistance of the platinoid. The rise of resistance of platinoid per degree C. is about 0·00023; multiplying this by 15 and we have 0·00345 ohm as about the actual increase of resistance due to the raising of the temperature from 15° C. to 30° C. Let us suppose also that the value of the coëfficient must be obtained to the fifth decimal place, or in other words that the resistance 0·00345 must be measured with a maximum error a trifle less than 0·00008 of an ohm. With the average slide wire bridge a skilled observer is able to set the slider, it may be assumed, successively, with an error of setting not less than about $\frac{1}{10}$ mm. Consequently $\frac{1}{10}$ mm. of the wire must measure at least as low as 0·00008 ohm, and hence the whole wire 1,000 mm. long will measure 10,000 times this or $\frac{8}{10}$ ohm. To measure even as low a resistance as this even to $\frac{1}{25}$ per cent. is not at all an easy matter by ordinary methods. In practice the resistance of a metre wire should be as much less than the value given above as possible as a greater *length* of wire would then be used when N or S were changed; its non-uniformity would, consequently, become relatively less important, and errors of setting would bear a smaller ratio to the whole length used. It would also be much better, if possible, to measure the resistance of the bridge wire in terms of the resistance of the standard itself, as we would thus eliminate any difference of adjustment between the single standard and any box which we might use for the purpose of measuring the resistance of

the bridge wire by ordinary methods. We are, indeed, able to very accurately use this method and apparatus in measuring its own bridge wire. To do this we merely place a heavy short copper strap of negligable resistance in place of X and a resistance Q, somewhat less than the resistance of the single wire, at the right (diagram of *Fig. 1*). Taking our two balances as before, we have from (6)

$$Q - o = \rho\,(x_1 - x_2) \therefore \rho = \frac{Q}{x_1 - x_2} = \frac{Q}{\delta_1} \qquad (8)$$

To find now, the resistance of Q place it in multiple with the standard S, at the right, and again determine the difference, in this case S_2, we shall have

$$\frac{Q\,S}{Q + S} = \rho\,\delta_2 \qquad (9)$$

and eliminating Q between (8) and (9) we have

$$\rho = S \cdot \frac{\delta_1 - \delta_2}{\delta_1\,\delta_2}$$

A third way, which I have used a great deal, is to place a standard one and ten-ohm coil in multiple upon one side against a standard one-ohm coil upon the other. In the early form which I have described it was very difficult to accomplish any of this placing in multiple as there was but one pair of mercury cups upon a side; consequently, we were obliged to make an accessory double pair of cups with connectors to hook into the regular standard cups; this introduced another mercury contact, in itself a bad thing, and also an additional copper resistance which disturbed the symmetry of the apparatus, and hence, the rigid accuracy of the equations preceding. In the improved design of apparatus which I have here, *Fig. 3*, provision has been made for the placing, if desired, of two coils upon each side, and this in a way which does not in the least disturb the original symmetry of the apparatus. In the diagrammatic sketch of this, *Fig. 4*, there is shown a ten- and one-ohm coil in multiple on one side against a one-ohm on the other side; observe, also, that the cups are so placed that the coils clear one another perfectly, and have ample room

about them for the necessary oil or water-bath. The distance between these cups is one and five-sixteenths inches, the usual distance between terminal coppers of the B. A. form of standard, which distance will, for the sake of uniformity, probably be retained by all instrument makers for a long time to come.

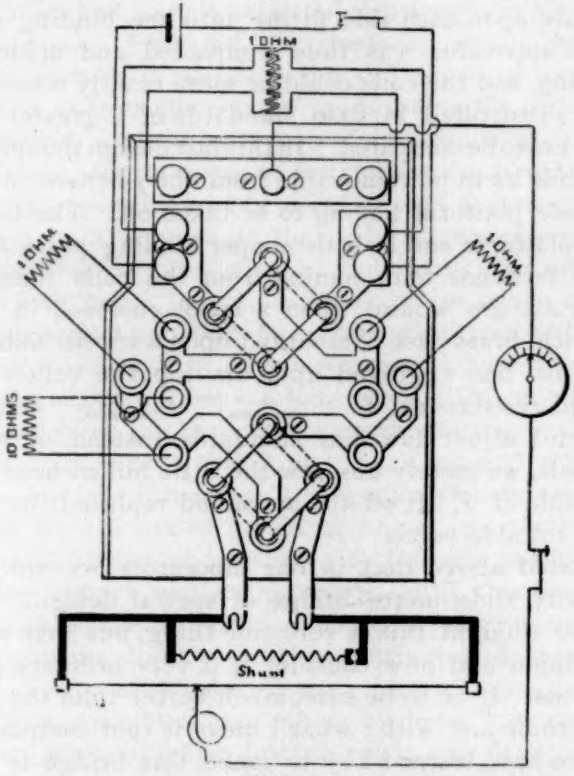


FIG. 4.

The resistance of the coils R_1 and R_2 disappears in the course of the measurement, as is seen from inspection of equations (5) and (6). It is hence not necessary that the *value* of these resistances be known; all that is desired is that they should be *approximately* of the resistance of the coils under comparison in order that the balance may fall near the centre of the wire, and that their resistance should

not change during the progress of the measurement. To insure this latter it is sufficient to wind the two coils upon the same spool, and in the first apparatus I ever made of this kind, while I was in the laboratory at Ann Arbor, these two coils were simply enclosed in a plain round wooden box. Later on it occurred to me, however, to place them upon a spool mounted upon a little stand having a pair of terminals upon each side fitting into the binding posts at *T*; the apparatus was thus compacted and made better appearing, and the coils could be more readily removed and others substituted in case standards of a greater or less value were to be compared. In this last design the spool itself is so made as to be removable from the *platform* instead of the whole platform having to be taken off. The terminals of the platform end in little copper binding posts *T*, which receive terminal rods coming from the coils themselves; these coils are wound upon a spool enclosed in a small cylindrical brass case *S*, mounted upon a rubber sub-base *P*. Each case has engraved upon its top the values of the enclosed resistances, as "$\overset{2}{\text{one-ohms}}$," "$\overset{2}{\text{ten-ohms}}$," etc. If we desire to adjust ten-ohm standards instead of one-ohm standards, we merely unscrew the little milled head screws, at the side of *T*, lift off the spool and replace it by another one of suitable value.

I stated above that, in our laboratory, we are using a three-wire slide metre bridge of special design. At one time we thought this a very fine thing, but have modified our opinion and now consider it a very ordinary piece of apparatus. It is, to be sure, much better than the average bridge to be met with; what I mean is that compared with what we have learned how to make, this bridge is quite a poor affair. In the first place, I believe any design of a Wheatstone's bridge which is intended for exact work is fundamentally bad if it makes use of a straight wire of any length stretched between two points. I have several reasons for this belief. A bridge used in the average laboratory cannot but be subjected to considerable variations of temperature from one time to another; sometimes this will not be over 5° or 10° for an entire month at a time;

again it may be 20° in about as many hours. As the bases of most slide-wire bridges have been of wood having a coëfficient of expansion considerably different from those of the German silver or platinum iridium wires mounted upon them, it is evident that their temperature variations must produce, at times, considerable strain upon the soldered junctions of wire and end pieces when the wire has been tightly stretched, and it *must* be tightly stretched if good work is done. Probably the greatest strain, however, does not arise so much from the difference of expansion coëfficients as from the change produced in the dimensions of the wooden support by reason of its absorbing or giving out moisture; for purposes of instrument construction it is practically impossible to find wood so well seasoned as not to deform in a very short time. It is, consequently, not surprising that very few straight slide wires ever remain in position very long. In fact, I have never yet seen a straight wire bridge upon a wooden base, with wire stretched tightly enough to make an accurate measurement, whose wire would hold fast without pulling out for a week. The only remedy is to either place the wire upon a compensating base or else to arrange the wire so that it may be slackened when not in use. In the "three-wire" bridge previously spoken of, the wires were fastened to sliding copper end plates which could be tightened and fastened to the end pieces proper by having copper connecting straps. But this having to tighten the wires is a nuisance, requires some strength, and is apt to mean slightly different settings and consequent lengths of wire at different times. I have here a design of a three-wire straight bridge which we have just completed and from which the first instrument is now being made in our shop. Instead of a solid base the support for the wires will be a skeleton frame work of brass rod, the coëfficient of expansion of which is not very far distant from that of the alloys which are usually used for bridge wires. A straight wire bridge has, however, still another defect, to my mind, fully as serious as the one mentioned. This is the tendency to the development of thermal currents, particularly where the wire is joined to the end coppers;

the ends of the wire being a metre apart it is entirely possible and indeed probable that differences of temperature will exist in the air at the two ends of the wire of sufficient amount to develop thermal electro-motive forces of very appreciable values. To make perfectly clear how important a consideration this is I must again refer to the theory of this "Carey-Foster" method. Let us assume that we are comparing two standard ohm coils together and that we wish to know one in terms of the other to an accuracy of $\frac{1}{200}$ per cent., *i. e.*, that we must have a deflection of the galvanometer needle when the slider is but $\frac{1}{20000}$ ohm from perfect balance. We will assume that we are using one cell of battery giving about one volt effective E. M. F. at the junction with the bridge arms. Since there are two ohms on each side the fall through $\frac{1}{20000}$ ohm is $\frac{1}{40000}$ volt. Let us also assume the bridge wire to be German silver, and the terminal ends to which the wire is fastened copper. The thermal E. M. F. of this couple assuming that the one end is at a temperature of 19° C. and the other at 21° C., a difference of but 2° C. is, according to Professor Tait's table of thermo-electric heights,*

$$\begin{aligned} \text{German silver} &\quad -1{,}207 - 5{\cdot}12\,t \\ \text{Copper} &+ \quad 136 + {\cdot}95\,t \\ &\quad -1{,}343 - 6{\cdot}07\,t \end{aligned}$$

$$\text{E. M. F. per degree} = -1{,}343 - 6{\cdot}07 \times 20 = 1{,}464 \text{ C. G. S.}$$

$$\text{E. M. F. of couple } 1{,}464 \times 2 = 2{,}928 \text{ C. G. S.} = \frac{3}{100{,}000} \text{ volt.}$$

This value just obtained is a trifle greater than the E. M. F. which must be detected by the galvanometer and will, of course, throw our observations out by exactly the same amount and prevent our obtaining the required accuracy. If this happens when there is only 2° difference between the ends and when but $\frac{1}{200}$ per cent. is aimed at, how will it be when there is 4° or 5° difference, as there often is, and an accuracy of $\frac{1}{300}$ or $\frac{1}{400}$ per cent. to be attained, and in addition innumerable other thermal E. M. F.'s due to other portions of the apparatus?

* Everett's *Units and Physical Constants*, 2d ed., pp. 174.

Of course, there are other ways of eliminating the influence of thermal currents. The simplest is to use the galvanometer in place of the battery and to close the battery circuit upon the bridge wire. This plan is, however, not to be recommended. Another good way is to reverse the battery current, the thermal E. M. F., thus acting at one time *with* and at another *against* the battery E. M. F.; the mean of the two is then the balance reading. This is easily accomplished in the apparatus which has been diminished by first taking readings with commutators turned parallel and then with commutators at right angles; *e. g.*, (*Fig. 5*), there would be four commutator positions necessary, as below:

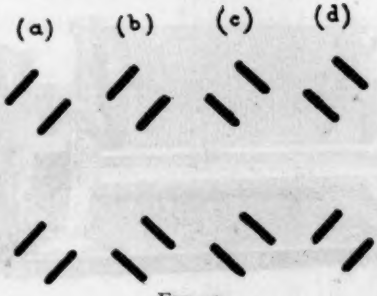


FIG. 5.

The difference of the mean of (*a*) and (*b*) and the mean of (*c*) and (*d*) would represent the desired difference between *X* and *S*, which we desire.

The orthodox straight-wire bridge also occupies considerable space and spreads the apparatus necessary for many of the more common measurements out in an undesirable manner, besides in the case of regular Wheatstone bridge work requiring one to get himself into all sorts of impossible positions in order to obtain and read his balance. On account of all these reasons, I personally favor a wire bridge, having the wire bent one or more times about a circle or cylinder rather than the straight-wire pattern. A circular-wire bridge, if well made, does all that the straight pattern will do and does it much more conveniently; it occupies but little space and brings the readings where they can easily be read; the ends of the wire are close together, so that there is prac-

tically no difference in temperature between them and the form is necessarily such that the wire cannot pull out of the end junctions. The contact also is usually a rolling wheel contact giving a tangent point of contact, and hence is not liable to injure the wire, as are most of the cutting "knife edge" contacts on the usual forms of straight bridge. These conclusions as to the relative efficiency of straight and circularly laid wires in slide-wire apparatus are not merely theoretical; they are practical, having been founded upon my own personal experience with both types in the making of very accurate measurements, and upon the experience of those associated with me, who are using the method every day in commercial work.

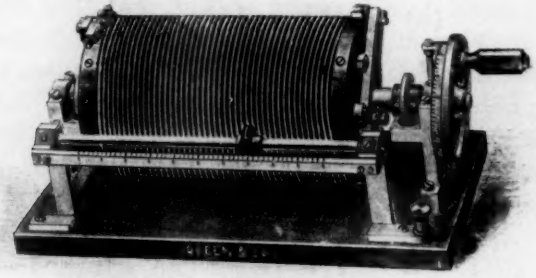


FIG. 6.

I have, therefore, designed and constructed a cylindrical arrangement of bridge wire to go with this latest form of commutating device just described. This is shown in *Fig. 6*, and in diagram in *Fig. 7*. The wire is here coiled upon a polished hard rubber cylinder 4 inches in diameter and 7 inches long; this cylinder is highly polished and the wire stretched in a screw thread cut in its surface. There are fifty turns of wire upon the cylinder. In front of the cylinder is a scale running the entire length of the cylinder, and between the cylinder and scale a small wheel sliding upon a bar carried by the same supports as the scale. This wheel bears snugly against the wire, the end supports being strips of spring brass. Its circumference is platinized and turned to as true a circle as possible, so that the tangent contact is very sharp and definite. As the cylinder is caused to revolve upon its axis, by turning the handle at the end, the little

contact wheel travels along the scale always in contact with the wire. The long scale indicates how many complete turns have been made. In order to obtain the fraction of a turn the wheel at the end is divided into 100 parts and each of these parts is easily divided, by the eye, to tenths. This graduation is read by reference to a zero mark at its side, visible in the cut. The bridge wire is thus divisible into $50 \times 100 \times 10 = 50{,}000$ parts. In order, however, to measure accurately the extremely small resistances represented by the increase of resistance of (say) a platinum silver one-ohm standard for 10° C. increase of temperature, we must have a lower resistance bridge wire than could be obtained by bending any *flexible* wire upon a cylinder but four inches in diameter. The wire has, consequently, been

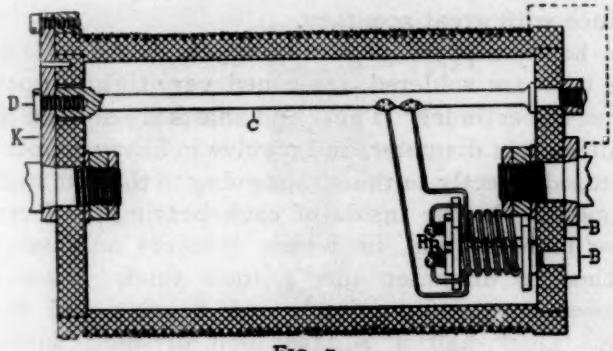


FIG. 7.

shunted by two shunts placed inside the cylinder itself; these shunts are such that the total resistance of the bridge wire may be either one-ohm or $\frac{1}{10}$ ohm, as desired, and are arranged so that either may be used by simply plugging in a small plug at the end of the cylinder. If we use the $\frac{1}{10}$ ohm shunt the smallest difference measurable with the combined apparatus is $\frac{1}{50000} \times \frac{1}{10}$ ohm $= 0{\cdot}000002$ ohm; it is thus easy to measure with great accuracy extremely small differences between two coils or to determine temperature coëfficients, even though extremely small.

The method of arranging the shunts in this apparatus is worthy of notice; they are so placed that their adjustment, by the maker is easy and convenient. Referring to *Fig. 6*,

the shunts are each mounted upon rods *R*, screwing into the end blocks *B*; one end of each shunt is soldered to its rod. The other ends of each shunt are soldered to the rod *C*. In adjusting, the right-hand head of the cylinder is slipped out of position, carrying with it the shunts and rod *C*; the shunts are adjusted as accurately as possible and the head slipped back. As the head slips into place the rod *C* shoulders against a heavy copper strap *K*, connecting with the left-hand end of the bridge wire. A copper screw *D* then taps into both the strap *K* and rod *C*, thus making a clean, fresh screw connection between them; a careful measurement of the total resistance is now made, the amount of necessary correction noted and the head again slipped out. A very few trials will suffice to get the desired resistance with great accuracy.

The heavy copper end straps, to which the ends of the bridge wire are soldered, are coned very tightly upon the shafts of the cylinder. These end shafts are of solid copper one-half inch in diameter, and revolve in heavy copper bearings brazed directly to the straps going to the commutating attachment. On the inside of each bearing is formed a massive mercury cup, in which revolves a copper ring $1\frac{3}{8}$ inches in diameter and $\frac{1}{8}$ inch thick; these rings have been sprung upon each end bearing and fit very tightly. Over half a square inch of their surface is always under the surface of the mercury, which is always kept at the same height. The surface of copper contact is so large and the thickness of mercury so small that the resistance at these places is negligable; it is also constant. A sliding brush contact will not answer for work of this kind, as the contact resistance is apt to be variable. In order to prevent the mercury from spreading, by capillary attraction, over the adjacent copper surfaces, each copper ring is clamped, just outside the shaft, between rubber washers recessed and filled with sticky wax. This wax, pressing against the copper, will, it is hoped, aided by the thick bands of lacquer, keep the mercury in its proper place.

Particular attention must be drawn to the fact that every particle of metal forming, in any way, part of the circuit or

in contact with it, is of copper in both the commutator and cylindrical bridge with the exception of the wire itself. This is necessary not only to keep the resistance of the circuit small, but also to avoid *thermal currents and contact E. M. F.'s.* In the earlier apparatus referred to in the first part of this paper, it has been impossible to do the highest grade of work without thoroughly wrapping a large part of it in cloths or paper to keep down the thermal currents, and this, despite the fact that about the only metal *except* copper, was in the binding posts; these, however, are sufficient to generate disturbing E. M. F.'s of sufficient magnitude to effectually mask the results desired, and it was seen to be imperatively necessary to get rid of this *entirely.* In the present apparatus the binding posts, connectors, cups,

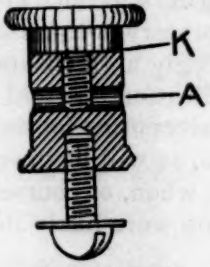


FIG. 8.

shafts, shunt rods *C* and *K*, the terminal blocks of the shunt coils and all are copper; only the junctions of the wire itself can possibly give trouble, and this, experience has shown, need not be feared in the cylindrical bridge.

It is obvious that by simply replacing *X* and *S*, *Fig. 1*, by negligable resistances we convert the arrangement into the simple Wheatstone's bridge. Hence, in the apparatus in *Fig. 3* we need but to place short, heavy copper wires in place of the standards on each side to enable us to use the device for ordinary work.

Often it is desirable to measure spools of wire quite accurately (say to $\frac{1}{20}$ per cent.), as, for instance, in the adjustment of a high-grade resistance box, where the coils must be as accurate as possible before putting into the set since any adjustment *then* would involve the loosening and

re-making of a solid joint and much inconvenience. With this apparatus this work can be done in one-fifth the time necessary with the usual apparatus, and with a more certain accuracy. Since, in such cases, it would not be worth while to solder wire ends to heavy coppers for immersion in the mercury cups, and since, indeed, the accuracy wanted does not require it, binding posts have been provided for this purpose just back of the mercury cups. These posts are of the "double grip" style, designed by Queen & Co. (shown in section in *Fig. 8*), and will catch the finest wires securely, either in the hole *A* or between the surfaces *K*; the resistance of quite heavy copper conductors may thus be measured.

Many results obtained with and showing the performanec of this apparatus might be given. The following, transcribed from one of our laboratory note-books, is sufficient, however, to show the exceedingly high accuracy obtainable. It is the record of a standardization of a coil recently sent to us by one of the large universities for an exact determination of its value. The data, as will be observed, were obtained on four different days, when, of course, minor conditions and the personal equation were likely to be very different.

ELIOTT OHM, NO. 106.

(*a*) October 27, 1892.	
Millimetres to balance, . . — 358·3	value in ohms, . . — 0·01250
Temp. of standard (E No. 186), 13°·0 C.	value of standard, . . 0·99675
Temp. of ohm (No. 106), . . 13°·25 C.	value of ohm No. 106, 0·98425
(*b*) October 27, 1892.	
Millimetres to balance, . . — 355·0	value in ohms, . . . — 0·01239
Temp. of standard (E No. 186), 12°·7 C.	value of standard, . 0·99667
Temperature of ohm No. 106, 13°·3 C.	value of ohm No. 106, 0·98428
(*c*) October 27, 1892.	
Millimetres to balance, . . — 429·3	value in ohms, . . — 0·01502
Standard (A), ... ——	value in standard, . 1·00608
Temperature of ohm No. 106, 42°·1 C.	value of ohm No. 106, 0·99106
(*d*) October 27, 1892.	
Millimetres to balance, . . — 424·8	value in ohms, . . — 0·01487
Standard (A), ... ——	value of standard, . . 1·00608
Temperature of ohm No. 106, 42°·3 C.	value of ohm No. 106, 0·99121

(*e*) October 28, 1892.

Millimetres to balance, . .	— 171·4	value in ohms, . . — 0·02091
Standard (A), ...	——	value of standard, . . 1·00608
Temperature of ohm No. 106,	18°·0 C.	value of ohm No. 106, 0·98517

(*f*) October 28, 1892.

Millimetres to balance, . .	— 596·3	value in ohms, . . — 0·02087
Standard (A), ...	——	value of standard, . . 1·00608
Temperature of ohm No. 106,	18°·1 C.	value of ohm No. 106, 0·98521

(*g*) November 7, 1892.

Millimetres to balance, . .	— 293·9	value in ohms, . . — 0·01029
Standard (B), ...	——	value of standard, . 0·99588
Temperature of ohm No. 106,	18°·1 C.	value of ohm No. 106, 0·98559

(*h*) November 10, 1892.

Millimetres to balance, . .	— 284·3	value in ohms, . . — 0·00995
Standard (B), ...	——	value of standard, . 0·99587
Temperature of ohm No. 106,	19°·5 C.	value of ohm No. 106, 0·98592

(*i*) November 10, 1892.

Millimetres to balance, . .	— 284·8	value in ohms, . . — 0·00997
Standard (B), ...	——	value of standard, . 0·99585
Temperature of ohm No. 106,	19°·3 C.	value of ohm No. 106, 0·98588

ACCURACY OF RESULTS.

Date.	*Test.*	*Value.*	*T*—° C.	*Accuracy of Agreement with Temperature Coëfficient Applied Between.*
October 27, 1892	(*a*)	0·98425	13°·25 C.	
				(*a*) and (*b*) $\frac{1}{500}$ per cent.
October 27, 1892	(*b*)	0·98428	13°·3 C.	
October 28, 1892	(*e*)	0·98517	18°·0 C.	
				(*e*) and (*f*) $\frac{1}{500}$ per cent.
October 28, 1892	(*f*)	0·98521	18°·1 C.	
November 7, 1892	(*g*)	0·98559	18°·1 C.	
				(*g*) and (*h*) $\frac{1}{500}$ per cent.
November 10, 1892	(*h*)	0·98592	19°·5 C.	
November 10, 1892	(*i*)	0·98588	19°·3 C.	(*g*) and (*i*) $\frac{1}{1000}$ per cent.
				(*h*) and (*i*) $\frac{1}{1000}$ per cent.

DETERMINATION OF TEMPERATURE COËFFICIENT.

(1) From (*c*) we have . . . . . 0·99106 ohms at 42°·1 C.
From (*e*) we have . . . . . 0·98517 ohms at 18°·0 C.

Difference is . . . . . 0·00589 ohms for 24°·1 C.

$$\therefore \text{Temperature coëfficient} = \frac{0{\cdot}00589}{24{\cdot}1 \times 0{\cdot}98517} = 0{\cdot}000252$$

(2) From (*d*) we have . . . . . 0·99121 ohms at 42°·3 C.
From (*f*) we have . . . . . 0·98521 ohms at 18°·1 C.

Difference is . . . . . 0·00600 ohms at 24°·2 C.

$$\text{Temperature coëfficient} = \frac{0{\cdot}00060}{24{\cdot}2 \times 0{\cdot}98521} = 0{\cdot}000252$$

SUMMARY.

Between October 28th and November 7th, the temperature was, at times, very low. This caused the increase noted in (*g*), (*h*) and (*i*) over (*e*) and (*f*). The fall between (*a*), (*b*) and (*c*), (*f*) was due to the heating to which the coil was subjected in (*c*), (*d*). This coil, No. 106, was of platinum silver, and this *permanent increase* if subjected to low temperatures and decrease if too high temperature are well-known characteristics of the alloy. The present value of the coil is given by (*g*), (*h*), (*i*): this value holds, providing the limits 12°·0 C. and 25°·0 C. are not exceeded. After noticing the permanent change in resistance above referred to, I wrote to Professor Carhart, who had sent us No. 106, telling him of it and saying that it probably occurred as a result of the heating necessary in getting its temperature coëfficient, but did not give him the coëfficient we had obtained. In his letter of reply, he said: "I meant to tell you not to heat the standard, as we have very carefully determined its coëfficient. It is not over 0·00025, I think." This, as contrasted with our value given above, is a difference of but $\frac{1}{50}\frac{1}{00}$ per cent., and shows how close work can be done with the apparatus in the hands of different observers in different places at different times.

Since the preceding portion of this paper was written, considerable additional work of the character which has been discussed has been done under my direction, with the previously described, and kindred forms of, apparatus. The results have been even more gratifying than those which have been given.

In connection with the work another new design of the apparatus has been produced which may seem to some to offer points of further advantage. The new design is shown in perspective in *Fig.* 9. As will be noted, the bridge

and commutator are here combined in one piece so that the apparatus is complete in itself. The arrangement is, upon

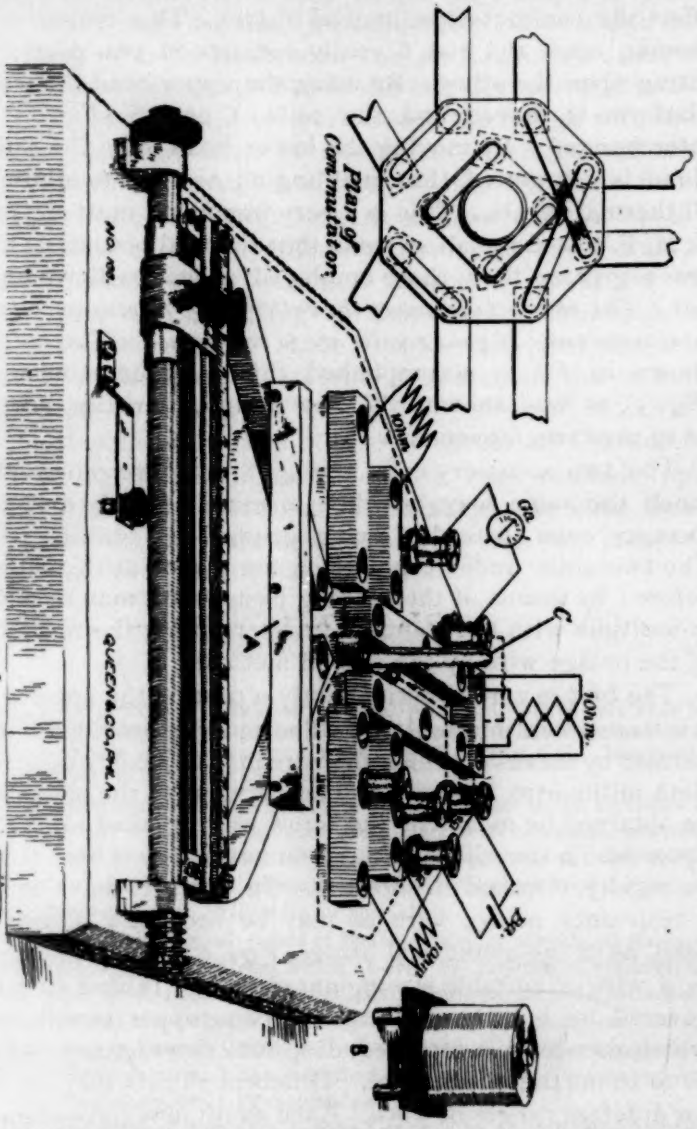


Fig. 9.—Improved bridge for comparing standards of resistance.

the whole, exactly the same as that shown in *Fig. 3*, the principal differences between the two being in compactness

and simplicity of construction. The two commutators of *Fig. 3* are so arranged that but *one* movement is required to effect the commutation, instead of two. This commutator, moving upon the rod *C*, really consists of two parts, one fitting upon the other. By using the upper head the whole platform is moved and the coils *X* and *S* (*Fig. 1*) are interchanged. By moving the lower head only, the *battery* alone is commuted, thus enabling us *perfectly* to eliminate all thermal effects. This is a very important matter, as the E. M. F.'s used are all so small that thermal potentials may prove greater than those employed, as was earlier pointed out. *The ability to commute the battery only is, consequently, of vital importance if good results are to be attained.* The pattern shown in *Fig. 3* accomplished this by four movements (*Fig. 5*), as was shown; the new design, therefore, enables us to save two movements.

The two accessory coils *S*, *Fig. 3*, are here mounted in much the same way, but their terminals simply drop into mercury cups instead of being gripped by binding posts. The two coils under comparison are placed at the sides as before; by means of the binding posts a coil may be placed in multiple with the standard in determining the resistance of the bridge wire by the second method.

The bridge wire is permanently a part of the apparatus; it is twenty centimetres long. The slider is provided with a vernier by means of which the wire may be read to one-twentieth millimetre. A very fine adjustment of the slider may be obtained by means of the screw nut attached to the rod upon which the slider usually moves, but to which it may be rigidly clamped if desired. In order to have as low a resistance bridge wire as may be necessary, shunts are used, as in the cylindrical bridge, *Figs. 6* and *7*. The shunt is a wire of suitable size mounted upon a rubber strip and covered by a little zinc box *A*; two copper terminals, to which the shunt is attached, drop into two mercury cups so as to shunt the bridge wire. Different shunts may be used for different ranges of work. Each shunt may have stamped upon it the value of resistance of unit bridge wire division obtained by its use. This mode of varying the resistance

of the bridge wire is much superior to the employment of a number of wires which may either be bodily changed or with which may be used an adjustable slider which may be placed so as to run above any particular wire desired. The greatest advantage lies in the fact that using shunts it becomes worth while to work down the bridge wire until it is perfectly uniform in resistance; a shunt will then merely lower its total resistance. If the wires are bodily changed either this large amount of labor must be applied to each one or else a different calibration curve must be used for each wire. Another objection would be the difficulty of always getting the same contact resistances at the ends of the wire; if made with mercury they would be variable, owing to the instability produced by the contacts of the slider.

The apparatus is very simple to make, all the copper work being ordinary market-copper bars one-half inch square and bent into the required shape, the cups being drilled in the bars themselves. It is also very compact, measuring but 11 x 10½ inches over all.

BOOK NOTICES.

Highway Construction. Designed as a text-book and work of reference for all who may be engaged in the location, construction and maintenance of roads, streets and pavements. By Austin T. Byrne, C.E. New York: John Wiley & Son. Pp 685. Price, $5.

At a time when there is so great interest manifested in the highways of our country any work touching upon the subject must command attention, and the author has conferred a service in compiling, so far as possible, data from every available source, digesting and classifying it in such manner as to make this work an encyclopædia for specialists.

Amongst the many good points of the book may be mentioned his list of the literature of the subject from which he drew his inspiration, although we fail to notice in it some of the standard authorities, such as McAdams, McNeill, Telford, the Consular Reports of the State Department on "Streets and Highways in Foreign Countries," 1891, so rich in precedent, as well as the comprehensive compilation published in 1890, by the *Engineering and Building Record*, entitled "Pavements and Roads."

The broad scope of this work is shown at once by an enumeration of its chapter headings, beginning with Pavements and their Materials; Stone, Wood, Asphaltum, Brick, Broken Stone; Miscellaneous: continuing through

Foundations; Resistance to Traction; Location of County Roads; Width and Section; Earth Work—Drainage and Culverts; Bridges; Retaining Walls; Protection Works; Tunnels; Fencing City Streets; Footpaths; Curbs, Gutters; Reconstruction of County Roads; and closing with Maintenance; Trees; Specifications and Contracts; Implements and Prices. There are ninety tables of reference of various kinds and of great value, pertaining to roads. In short, there is hardly anything belonging to the subject that does not appear to be contained in the work in one form or another. It is a fund of knowledge for which the price is no equivalent. The book is simply invaluable and takes rank with its companion, which it resembles in many particulars, edited by Prof. Ira O. Baker, on "Masonary Construction." The publishers are to be congratulated on these two works, and the profession will be benefited by more of the same sort on other specialties.

It is to be regretted, however, that the diagrams are not better, for although they serve their purpose, the appearance of the book, as to its make-up, is marred by the crude and unskilful work in the preparation of many of the cuts (*vide* p. 56, *et al.*). There are a few points upon which we venture to suggest that the author's comments may lead to expensive constructions which may not be justified in practice, *e. g.*, he says: "Wide streets add materially to the commercial prosperity of a city," etc., and "A street which is likely to become a commercial thoroughfare should have a width of not less than 120 feet," etc. (p. 386). We know of very few business thoroughfares so wide as 120 feet. Parks and boulevards may equal and even exceed this width, but we hold that it is not economical to make either a street or road a foot wider than is necessary for traffic, since it adds to the expense of maintenance, increases distances, reduces the taxable or productive areas through which it passes and becomes a burden and often a nuisance instead of a blessing.

There is a ratio between the street and building area which will vary with the character of the business, latitude and physical conditions incident to the city. In general it may be said that the street areas should not exceed 33 per cent. of the total built-up territory, and the widths of the streets should be largely a function of the number, size and character of the vehicles traversing them. In American cities where the sidewalks are frequently used for storing or displaying wares they need to be wider than abroad where such practices are not allowed.

On pp. 66 and 67 are shown two granite blocks intersections differing materially the one from the other, one being fairly good the other bad, but with the same captions, "intersection paved with granite blocks," and having no adjacent description stating their relative merits, neither is there any reference to *intersections* in the index or under pavements where we could expect to find it, but under "*paving at street junctions*," there is a reference to p. 61 where, without a distinctive heading is an allusion to the cuts on pp. 66 and 67 as being alternate designs, one merely affording better foothold. The author has apparently failed to recognize that the weakest point of all rectangular pavements is the *joint in the direction of traffic* which soon

becomes rutted by the *wheel*, hence he accepts and states some conclusions which do not give the practical results in the manner of laying the blocks. There is also room for a brief digest of some of the best patents on the subject of various kinds of pavements and modes of laying. On the whole, however, as we have already stated, the book is one which no one interested in the subject can afford to be without, and we can cheerfully commend it to the student, supervisor, engineer or even the taxpayer who may think he "knows it all," but who will find here something not yet dreamed of in his philosophy. L. M. H.

Useful Information and Data for Travellers, Railwaymen and Mechanics. Compiled by T. R. Nichols. Second edition. Chicago: Danks & Co. 1892.

Mr. Nichols has succeeded in crowding in the space of sixty-eight pages of a small pocket book a collection of facts, figures and information about railroad construction and operation, methods of construction and miscellaneous data of value to the mechanic, that ought to serve a useful purpose. The contents of the book is well indexed. As our copy is entitled a second edition, the work would appear to have demonstrated its *raison d'être*. W.

Electricity and Magnetism. Being a series of advanced primers of electricity. By Edwin J. Houston, A. M., etc. New York: The W. J. Johnston Company, Limited, 41 Park Row. London: Whittaker & Co. 1893.

This volume may be considered as an expansion of the admirable series of primers first prepared by the same author for the information of the visitors to the International Electrical Exhibition, held under the auspices of the Franklin Institute in the year 1884. At that time, the general public was practically in dense ignorance of the subject of electricity and its applications, but in the eight years that have elapsed since then, the public has been educated to such an extent that the extremely elementary instruction contained in the original primers, requires to be supplemented by information of a more advanced character.

This information Professor Houston has supplied in the present volume and supplied in his usual happy style.

This volume contains eighteen primers in all, the last one being a review, or "Primer of Primers," which sums up the salient features of the different topics treated. The subjects of the different primers relate to the various sources and phenomena of static and current electricity, and of magnetism, with practical deductions and applications. Atmospheric electricity and the phenomena of the earth's magnetism receive a particularly interesting treatment, and the primers on the electro-magnet, electro-receptive devices and frictional and influence machines are very practical in their scope.

A feature of the work is the abstracts from standard electrical authors at the end of each primer, which generally have reference, and furnish an extension, to some important point in the primer, and at the same time give the reader an introduction to electrical literature.

While the work is primarily intended for popular reading, the care of statement and logical development of principles make it a valuable work for electricians who wish to gain a knowledge of, or to review, the principles upon which the science is based. W.

Franklin Institute.

[*Proceedings of the annual meeting, held Wednesday, Jan. 18, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, January 18, 1893.

MR. JOS. M. WILSON, President, in the chair.

Present, 174 members and thirteen visitors.

Additions to membership since last report, sixteen.

The Secretary presented the annual reports of the Board of Managers, of the several standing committees, of the Chemical and Electrical Sections, and of the Trustees of the Elliott-Cresson Fund, which were duly approved.

The tellers of the annual election, held this day between the hours of 4 and 8 P.M., presented their report, which was accepted, and the tellers were discharged with a vote of thanks.

The President thereupon declared the result of the election, as follows:

For *President*	(to serve one year), . . .	JOSEPH M. WILSON.
" *Vice-President*	(" three years), . . .	CHARLES BULLOCK.
" *Secretary*	(" one year), . . .	WM. H. WAHL.
" *Treasurer*	(" " "), . . .	SAMUEL SARTAIN.
" *Auditor*	(" three years), . . .	SAMUEL H. NEEDLES.
" "	(in place of Wm. A. Cheyney, deceased), .	FRANCIS LECLERE.

For the *Board of Managers* (to serve three years).

CHARLES H. BANES,	WASHINGTON JONES,	STACY REEVES,
F. LYNWOOD GARRISON,	ISAAC NORRIS,	COLEMAN SELLERS.
J. HOWARD GIBSON,	THEODORE D. RAND,	

For the *Committee on Science and the Arts* (to serve three years).

ARTHUR BEARDSLEY,	G. M. ELDRIDGE,	EDWARD F. MOODY,
HUGO BILGRAM,	F. L. GARRISON,	E. ALEXANDER SCOTT,
FRANK P. BROWN,	REUBEN HAINES,	COLEMAN SELLERS,
JOHN H. COOPER,	JOHN HALL,	H. W. SPANGLER,
N. H. EDGERTON,	ARTHUR KITSON,	WILLIAM H. WAHL.

Mr. George D. Burton, of Boston, Mass., read a paper on his system of electric forging, describing the method and special apparatus employed, and

illustrating the subject with a large number of interesting specimens of the work produced, and by lantern slides exhibiting the details of the various machines and devices employed. The paper was referred for publication.

Prof. Edwin J. Houston gave a brief sketch of the principle of operation of the gramophone, invented by Mr. Emile Berliner, of Washington, pointing out especially the substantial differences in the record-making process between this apparatus and the phonograph and graphophone. The members were then given the opportunity of hearing the reproduction of a number of musical pieces, recitations, songs, etc., which were rendered with sufficient loudness to be distinctly audible all over the lecture-room, and with remarkable fidelity.

The thanks of the meeting were voted to Mr. Burton and to Mr. Berliner for their interesting contributions.

Adjourned.

WM. H. WAHL, *Secretary.*

BULLETIN FOR THE MONTH OF FEBRUARY, 1893.

TO MEMBERS OF THE INSTITUTE:

The Stated Meeting will be held on

WEDNESDAY, FEBRUARY 15, 1893, at 8 o'clock, P.M.

The following program has been approved by the Committee on Meetings:

Mr. JAMES M. PRICE will read a paper on his "Improvements in Rail Joints," with suitable illustrations.

Prof. ANGELO HEILPRIN will give a popular account of the recent expedition for the relief of Lieut. Peary, illustrating his remarks with a series of lantern views.

Mr. JOHN M. HARTMAN will exhibit a series of interesting views of Ancient Egyptian Architecture, with appropriate comments thereon.

WM. H. WAHL, *Secretary.*

SCHEDULE OF MEETINGS.

Committee on Science and the Arts,	Wednesday, Feb. 1, 8 P. M.
Committee on Library,	Monday, Feb. 6, 4 P. M.
Board of Managers,	Wednesday, Feb. 8, 8 P. M.
Chemical Section,	Tuesday, Feb. 21, 8 P. M.
Committee on Meetings,	Wednesday, Feb. 22, 5 P. M.
Electrical Section,	Tuesday, Feb. 28, 8 P. M.

☞ MEMBERS are requested to present to the library copies of books, magazines and pamphlets (especially the latter), which they do not wish to preserve. A card addressed to the Librarian, notifying him when and where to send for such gifts, will receive prompt attention.